Understanding the role of value in coral reef science

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For Pagett and Harry, who both liked to think.

Abstract

This thesis explores the role of value in coral science from the perspective of philosophy of science in practice. More specifically, it looks at the epistemology of different practices and theories in coral science, particularly how they interact with various forms of value, and how these forms of value can be understood. The arguments are organised into five chapters, which all make use of data collected in interviews with coral scientists, as well as ideas from coral science literature. The first presents an examination of ecological baselines, which I show do not simply 'shift' as has been supposed, but vary for a variety of reasons. This raises a question I address in the second chapter: when is this variation considered legitimate? The answer depends on the value of different reef states being considered. After showing how coral scientists navigate this in practice, I move on to the next two chapters where I explore areas of coral science where important forms of valuation take place: first, the value frameworks of intrinsic value and ecosystem services; and second, the use of bioacoustic techniques to assess reef health from non-human perspectives. These offer examples of how different forms of value shape coral science and make it relevant to the lifeforms practising and influenced by it. In the final chapter I present a view of coral science as a form of multispecies niche construction, both in the lab and the field. On this view, coral science is aimed at the flourishing of a range of living systems. This offers a better understanding of science-value interactions in socio-ecological contexts, such as when faced with decisions about baselines and interventions designed around these. Understanding how to navigate such situations is likely to become increasingly important as the challenges of surviving as a species continue to mount.

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Abbreviations

Abbreviations are defined in-text when first used, but also listed here.

ES – Ecosystem Services

GDPR - General Data Protection Regulation

NGO – Non-Governmental Organisation

PSP – Philosophy of Science in Practice

SBS – Shifting Baseline Syndrome

STS – Science and Technology Studies

Introduction – The philosophy and sociology of coral reef science

> "In shape coral is like a shrub, and its colour is green. Its berries are white under the water and soft; when taken out they immediately harden and grow red … The most valued coral is the reddest and most branchy … At the present day it has become so scarce because of the price it will fetch that it is very rarely to be seen in the countries where it grows." Pliny the Elder in *Natural History,* circa 77AD (1938, pp.477–479)

Throughout the four years or so that I have been thinking about this thesis, I have been asked by people to explain it, or in other contexts to simply introduce what it is I am studying. The answer I have tended to give is that I study the philosophy and sociology of coral reef science, with a focus on value. Typically, this invokes further questions: The philosophy of corals? The sociology of sea creatures? Are you studying their feelings? Are you going to MRI scan them?

One way this often plays out is that people ask if I am studying coral reefs, or coral reef researchers. Particularly in the early days of this thesis, I did sometimes describe the project as *studying the people that study coral reefs*, and that has indeed been a large chunk of what I have done here: talking to scientists, reading what they write, attending their conferences, thinking about their practices. But I have also tried to learn about corals and reefs themselves, and about all the other things involved in coral science, including getting in the water myself (although, global exigencies considered, never actually seeing a coral reef in person[1]). I decided quite early on that my focus was not just on corals, or on coral scientists, but on the combined reef-human system, in all its ecological, social and epistemic guises. I wanted to see coral science alongside the ecological fluxes and flows, economic extractions and evaluations, cultural and social significances, and human and non-human worlds associated with reef systems. That is what I hope this thesis embodies: an enthusiastic engagement with the social, scientific, and ecological world of coral reef science, contributing in the process to a richer understanding of the epistemology of coral science practice, including a strong focus on the ecological dimensions of scientific activity, as well as an account of the interrelation and significance of various forms of value within this. In this

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[1] A member of the university diving club was kind enough to point out a pink sea fan - a type of zany soft coral found in British waters - to me in Cornwall in June 2023. So I finally got to see a coral in the wild, but not a reef.

introduction, I provide some context about corals, reefs, coral science, and the structure of this thesis, along with a look at some of the theory which has guided the project.

What are coral reefs?

I focus throughout this thesis on a charismatic and troubled marine organism - the coral - kindly and somewhat inaccurately introduced by Pliny the Elder above. I also focus on a structure it helps build, the coral reef. Corals themselves are small animals within the phylum *Cnidaria* (along with things like jellyfish and hydra) which tend to produce calcium carbonite skeletons (Cairns, 2007, pp.311–312). They are often, for much of their lives, rooted firmly onto rocks or other structures, but as juveniles may drift or swim across the sea in search of homes (Sheppard et al., 2018, p.42). They live in various forms of symbiosis with things like algae, fish, and micro-organisms (Sheppard et al., 2017).

Most notably, coral polyps - small individual corals which make up bigger coral colonies – sometimes live with zooxanthellae, small algae which live inside coral and produce nutrients from sunlight for them, in exchange for a secure habitat. This relationship impacts things like the heat tolerance, appearance and consumption of resources of the coral (Rosenberg et al., 2007; Suggett, Warner and Leggat, 2017). Algae also have their own internal microbial communities (microbiomes) (Lawson et al., 2018). Interrelations between host and symbiont can quickly shift from mutualistic to damaging, and coral can survive the loss of their symbionts in some conditions (Baker et al., 2018). Bleaching, where reefs turn a ghostly white, is the breakdown of this symbiotic relationship (the symbionts provide much of the colour of the coral) (Obura, 2009).

Many corals do not have photosynthetic symbionts, deep sea ones particularly – there is no ‘photo’ there for the synthesis – but still live in interesting symbiotic relationships with things like deep-sea worms, which, when present, can tunnel through and damage the coral in ways which spur them to grow faster (Roberts, 2005). Corals have multitudinous reproductive strategies: they may grow clonally, release sex cells in synchrony with lunar cycles, hybridise, or engage in inherited chimerism (where parents and offspring both contain multiple genetic individuals but in different proportions (Rinkevich et al., 2016; Chan et al., 2018; Craggs et al., 2020; Epstein, Bak and Rinkevich, 2003).

Individuality, in corals, as with many other organisms, is not simply a dichotomous matter, but one of degree and transition (Pradeu, 2016). Corals have a range of symbiotic partners living inside, on, and outside of them, all of which influence the properties of one another and of the ecosystem (Rosenberg et al., 2007), and which are acquired from their parents or the environment (Suggett, Warner and Leggat, 2017). Coral systems stretch across scales: algal symbiont – coral polyp – coral holobiont – coral colony – coral reef. These organisms then are not simple individuals, but nested ones: not drops in the ocean, but oceans in a drop[2]. Corals, then, have ‘never been individuals’ in a simple sense: there is no one correct way to delineate the sets of living things constituting and constituted by them (Gilbert, Sapp and Tauber, 2012). Instead, there are lots of ways: they demonstrate acutely a kind of promiscuous individualism, where something can be carved up in many different legitimate ways (Dupré, 2012). This has implications which run throughout the thesis, including linguistic ones: I use the term ‘living system’ or ‘coral system’ where I want to include organisms, ecosystems and other parts or combinations of the stuff making up or made up by coral reefs.

Corals form reefs, which are large stone structures. Coral reefs are a Gaian figure, a large, primarily dead structure encased by a thin layer of life, a rock smeared in a layer of vital marmite[3], constituted by a variety of living beings living and being together in temporary and shifting alliances. More formally, a reef is a ‘persistent, positive topographic biogenic structure, rising up to the surface of the sea and characterized by its capability to resist hydrodynamic stress’ (Roberts et al., 2009a, p.22). A ‘reef’, from the old Norse for ‘rib’ initially denoted any ridge-like sea structure which was capable of damaging a ship, but has since come to refer to such structures at any depth (Roberts et al., 2009b, p.23). Reefs are now more likely to be discussed in the context of being threatened by humans than threatening them (Sapp, 1999, p.141). This shift in

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[2] A paraphrasing of 13th Century Persian poet Rumi

[3] “Coral reefs are gigantic structures of limestone with a thin veneer of living organic material—but what a veneer! Everything that is useful about reefs (to humans and to the rest of nature) is produced by this organic film, which is approximately equivalent (in terms of biomass or carbon) to a large jar of peanut butter (or vegemite) spread over each square metre of reef” (Hatcher, 1997 from Sheppard et al., 2018, p.35)

perceptions of reef ecosystems, from dangerous places to endangered ones, forms a key backdrop to this thesis, which I return to particularly in the final chapter.

What is a reef, really? In terrestrial terms, imagine a nest - made by bees, ants, grasshoppers and birds - that can only appear under certain temperatures and air currents. They are complex associations of animals (corals, fish, invertebrates, others), plants (algae, both inside and outside of the coral, and others), microbes, rock, and more (Sheppard et al., 2017). They arise only in certain situations which permit the kind of cross-species cooperation necessary. In short, coral reefs are a kind of agreement, made across phyla, which can persist within a certain set of ecological conditions, a kind of 'goldilocks zone'. Various forms of reef, made by different guilds of organism, have appeared and disappeared throughout history (Leinfelder et al., 2012; Veron, 2008). Even in contemporary reefs, many different organisms may be involved in a given case of reef formation, including algae, sponges, urchins, oil company executives and other invertebrates, or even seabirds and rats (Sheppard et al., 2017; Macreadie, Fowler and Booth, 2011; Graham et al., 2018)[4].

With the Anthropocene well underway, the multispecies agreement underlying reef ecosystems is rapidly unravelling in many places. Hotter seas with varying chemical compositions (from acidification and pollution) shift the reef outside of its goldilocks zone and cause the central pact between algae and coral to fall apart (bleaching), unravelling this along with a whole web of other ecological associations (Douglas, 2003). These changes sometimes give rise to new associations of organisms in their place (Leinfelder et al., 2012; Graham et al., 2013). Reef systems can be pushed into other stable states by different stressors, which may be driven, mitigated, or amplified by symbiotic organisms. The mass unravelling of the symbioses underpinning coral ecosystems represents a dire warning for the global biosphere. They are not just indicator

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[4] Oil rigs may be left at sea to form artificial reefs, which various organisms may attach to. Seabird populations influence the flow of nutrients onto reefs through their guano, and rats can have large impacts on seabird populations by eating their eggs.

species, but indicator ecosystems, canaries in the sometimes non-proverbial coalmine[5] (Braverman, 2018, p.80).

Why focus on coral reef science?

The case I am interested in here is coral reef science[6]. This is the study of coral reefs, broadly construed, often also including systems interconnected with them, such as algal reefs, seagrass, fisheries, and more. My initial interest in reef science stemmed from an interest in two things: extended physiology and non-human value. Coral reefs provide rich examples for both: with ambiguous and multiple boundaries, and with webs of interdependence, competition and indifference, they represent excellent sites for studying these phenomena.

Given the strangeness of coral reef biology, it is no surprise then that they offer figures of inspiration for thinking about the living world. Coral have often been used for thinking through – figuring - other ecological and social systems (Helmreich, 2016; Haraway, 2016; Hayward, 2010). Karl Marx considered them models of non-hierarchical organisation: 'In corals, each individual is, in fact, the stomach of the whole group; but it supplies the group with nourishment, instead of, like the Roman patrician, withdrawing it', and as an instance of the huge impacts ('rising from the depths') that collaboration between comparatively small ('puny, weak and contemptible') individuals can have (Marx, 1887, pp.257, 232). Coral reefs themselves are frequently compared to cities[7] (Helmreich, 2016, p.53), and the parallels between them show why: reefs are spaces of great diversity and richness, and are collaborative constructions of calcium carbonate which offer spaces for survival and flourishing, just as cities are

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[5] Interestingly, the use of canaries in coalmines was pioneered by biologist and philosopher J. S. Haldane, father of biologist and philosopher J. B. S. Haldane. Haldane senior also pioneered many of the decompression calculations which allowed for scuba diving and so for advances in coral reef science (Lang and Brubakk, 2009). It is doubly apt then that reefs have come to be described as canaries in the coalmine.

[6] I will sometimes call this coral science or reef science, without implying any difference between these, for the sake of brevity. There are, no doubt, differences between coral science, reef science, and coral reef science, but they also overlap heavily, and in conversation the terms often get muddled.

[7] This parallel is widely recognised, for example Coral Morphologic, an art group in Miami, have two projects exploring coral-urban analogies: one where corals are projected onto urban buildings (many made of reef rock) and another a livestream of an urban reef off the coast of Miami (Coral Morphologic, 2023). The Dreamworks film *Shark Tale* is also set in Southside Reef, an underwater coral city (Dreamworks Wiki, 2023).

(albeit some better than others)[8]. But there are other reasons to focus on reef science beyond just the nature of reefs.

Reefs have been sites of human interest for much of history. They are important in many different ways: for the survival of organisms inside, near and far from them; for the maintenance and existence of human societies and economies, with many humans depending on reefs for things like fish (for food), wave protection, cycling nutrients through local ecosystems, and cultural and recreational experiences (Moberg and Folke, 1999; Jones, 2007). They have, over a long period of time, generated a unique range of biodiversity, as well as an immense scientific and cultural importance to a large swathe of humanity. They offer a microcosm of the many ways that living systems can be valuable for one another, and so a perfect focus for a thesis interested in exactly this.

Corals also have other epistemic and affective roles, as natural laboratories, sources of great inspiration, and sites for bioprospecting (Helmreich, 2016). Coral scientists may spend time in these systems, observing them, conducting experiments on them, and bringing aspects of them into laboratories. They are a hotbed of various forms of activity and interaction, and the focus of considerable scientific study (Helmreich, 2016, p.60; Braverman, 2018; Sapp, 1999). Reefs played a key role in understanding the effects of radiation after nuclear weapons tests (Jones, 2007; Helmreich, 2016). Given the range of organisms and activities present, coral science represents an interesting case for developing a more socio-ecological understanding of science. They also offer a site of overlap between epistemic, ecological and economic concerns, amongst others, along with the precarity associated with the Anthropocene.

The threats faced by coral systems await many other systems, and the changes to both reefs and to reef science offer an insight into how these systems might look in the future. Just as many corals are in danger of losing their algal symbionts due to changes in the conditions of their existence, we too are in danger of losing our coral symbionts. Understanding coral science is particularly important the because of the socio-ecological pressures it is under. As many others have noticed, studying systems at the brink of (or beyond) collapse

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[8] Interviewees during this thesis also made such comparisons between reefs, cities, and forests, as important positive topographic structures visible at scale on the earth's surfaces. There was not space to explore this further here, but I intend to do so in future projects.

(Tsing, 2015), or mired in controversies and attempts at compensation and compromise (Dussauge, Helgesson and Lee, 2015a) offer fertile ground for studying value. Coral science here provides a model science for others: just as reefs are a model for endangered ecosystems, so reef science offers a model for endangered sciences, i.e. how science develops when the ecosystem it exists within is steadily disappearing. The pressures this entails can cause shifts in how that area of science operates, for example when reef ecologists adopt scientific practices and rhetoric from epidemiological and medical contexts because this offers the promise of better intervening to protect reefs (Ankeny and Leonelli, 2019). This is not to say that all sciences with endangered ecological bases will come to look like one another, but just that looking at sciences in such contexts offers a potential point of departure from existing understandings of science.

Not only this, but coral science is also a set of value-articulating practices (Vatn, 2009). There are norms about who can and should participate in coral science, how they can do this, what counts as data and evidence, how this is to be produced and conveyed, and how conclusions are reached (Vatn, 2009). These processes characterise reefs in value-laden ways (which I explore particularly in the first two chapters), prioritising aspects of reef systems in ways which are relevant to humans as socio-ecological entities. The various practices I explore throughout this thesis offer windows on this value, and show how knowledge and value are co-produced and intertwined (Sunder Rajan and Leonelli, 2013) .

There are good reasons to think that some other areas of science don’t and won’t resemble coral science. The situation of coral science is a fairly distinctive one – albeit similar to other areas of ecology and conservation biology - both in terms of the context it finds itself in and the funding structures associated with it: the primary object of study of coral science is in serious peril of disappearing, or at least drastically transforming into something very different; the funding for coral science comes primarily from governments, NGOs and philanthropists, a contrast to areas of science more exposed to profit motives (Helmreich, 2009, chap.3; Sunder Rajan, 2006). Privately funded science may have significantly different incentive structures (as may other areas of non-privately funded science). Priorities may differ, as may criteria for assessing and understanding scientific activity itself, science being increasingly recognised as a disunified set of inter-related practices (Dupré, 1993; Cartwright, 1999; Rouse, 2023b).

I also do not want to make claims here which go beyond the areas of coral science I have examined. Like the coral and the reef, coral science is a chimera of geological, molecular, microbial, ecological, behavioural, remote and intimate enterprises. I focus primarily on medium-to-large-scale ecological coral science here (with some other elements included, see the methodology section for more detail). This does not stop lessons learned from the study of ecological coral science being relevant elsewhere but does give reasons to be cautious in extrapolating from it to other areas. I return to the question of applicability at the end of the thesis.

What is this thesis about?

This thesis aims to make two main contributions: first, a contribution to understanding the nature of science, specifically coral science, and the epistemology of various practices within it. There are several particular practices I am interested in. I start with baselining, a mode of modelling which involves considerations about what an ecosystem ought to look like. This leads on to the question of how reef health is conceptualised and interacts with other scientific practices, covered in chapter two. These questions demand an understanding of the valuation practices in coral science, which I explore first in chapter three by looking at the use and relation of intrinsic and instrumental modes of valuation, and how these shape the way coral science is done, followed by an examination in chapter four on how bioacoustic techniques can be used to consider non-human values. Finally, in chapter five, I bring the previous topics together, using the idea of niche construction to offer a richer socio-ecological understanding of coral science, as a process which seeks not only to understand the world but to shape the environments of living systems within it.

Second, this thesis also makes a contribution to theory about the nature of value. The relentless symbioticity of reefs makes traditional conceptions of value borrowed from economics and ethics hard to maintain. Instead, borrowing from Haraway, I include recognition that living systems are bound to kill, injure, eat or pollute one another, and for our part we must find ways to do so properly

(Haraway, 2003, 2016, 2009). This thesis contributes to this by showing how value takes richer forms than the simple intrinsic/instrumental, epistemic/non-epistemic or anthropo/bio-centric dichotomies might have us suppose. The view of value I present here is a webbed one, where things live, flourish and die, on, in, with, and despite one another. This view of value comes to fruition in the final chapter, brought together with a socio-ecological view of coral science, to give a twist on existing accounts of value-ladenness in science, one which brings together theories around value from ecology, sustainability sciences, STS and philosophy, and which recognises science as a symbiotic enterprise, conducted by assemblages of organisms. The first two chapters of the thesis set up the importance and need for understanding value in coral science, the following two chapters explore some key forms of value – intrinsic, instrumental, and non-human - in more detail, and the final one brings these together to better understand both value and coral reef science. Where possible, I have also tried to make this thesis relevant to the practice of coral science with the hope of helping address some of the challenges it faces, and so have sought feedback on it from people in the marine sciences as well as those in science studies.

Theoretical background

Throughout this thesis I have engaged with the various literatures on value from social sciences, philosophy, ecology and sustainability sciences. My views on the nature of value have been informed by these literatures, specifically those on value-ladenness in science (e.g. (Kincaid, Dupré and Wylie, 2007; Elliott, 2022)); the entanglement of fact and value discussed by Putnam (2002) amongst others; and the role of both biological and social factors in influencing assessments of reef ecosystems, of the type discussed in medical contexts by Conley and Glackin (2021) or Kingma (2014). As well as engaging with coral science and philosophy literature, I also read and draw on science studies work, including Donna Haraway, Irus Braverman, Bruno Latour, Anna Tsing, and Stefan Helmreich.

Each of the disciplines I engage with here brings different connotations to the (already broad) term *value*. There are both advantages and challenges to this. I capitalise on the rich set of meanings associated with the term value in order to produce a socioecological account of coral science which is faithful to the nuanced and shifting ways which value is involved in interactions between reef systems, science, and society. The broad meaning of the term *value*, along with related notions of *values* and *valuing,* does however prevent this from being anything like a comprehensive study of all of the various forms of and roles for value in coral science. This research was also heavily shaped by the Covid-19 pandemic, which made some kinds of empirical research more difficult and others much easier.

What follows is the outline of the core theoretical starting points of the thesis: value as relational; a movement beyond the naturalism/normativism divide (i.e. meta-naturalism); a refusal to separate the social and the ecological; and the desire to connect discussions around values in science with value elsewhere, particularly value as related to organism-environment interactions. In the next chapter I go into more detail about the specific methodology I use throughout the project.

Value as relational

Value has many meanings and theories associated with these. I draw on various conceptions of value as part of this thesis: those which highlight processes such as choice, rejection and selection in driving value (Dolfsma, 1997, p.412; Dewey, 1949, p.66); those which treat value as linked to the modes and intensities of care and attention applied to some entity, where different forms of value are reflected in different motivations for this (Leonelli, 2016, p.63); those where value is related to the meaning of something for some agent (Tadaki, Sinner and Chan, 2017, p.5) and where value represents the contribution something makes to some goal or objective (Limburg et al., 2002). In all of these cases value is related to some living system: this system may be selecting and choosing, attending to and caring for, interpreting, or having its goals supported by, some aspect of its environment. This thesis starts from this recognition, i.e. that value is a key part of interactions between living systems and the world, and that this is relevant to a great many forms of life (Gilliand, 2021).

The nature of value has been beset by debates which it would be neither useful nor entertaining to continue perpetuating here. On one side is the view that value is an objective feature of the world, independent of valuation or valuer, or of perception or observation (already these are very different things to be independent from). In this objective sense, value is a property of the valued thing (Lee, 1940, p.627). Forms of value associated with this include some conceptions of intrinsic value (e.g. invoked in relation to beauty or morality (Batavia and Nelson, 2017, pp.367, 370)), as well as some accounts of economic value, such as some labour theories of value, which treat value as something added to an object through the physical transformations involved in labour (Dolfsma, 1997, p.403)[9]. Here, value can be discerned without consideration of contingency or perspective, i.e. how valuable something is, is simply a fact about it.

On the other side, there are accounts of value which emphasise the subject or observer. For example, in modern economics, value is often supposed to be the personal utility derived from the consumption of a good. This is a psychological and subjective notion of value, grounded in personal preferences (Dolfsma, 1997, p.405). Similar conceptions of value can be used when talking about the instrumental value afforded by something as contributing to a subjectively ascribed goal; or the affective value something holds for someone. Here, value is cast as psychologically derived add-on to the physical world, and as subjective and solely a product of the mind (Dolfsma, 1997, p.405). Value in this case becomes an object of study for psychologists, and, in some versions of this, humans are the only real sources of value, particularly if it is thought that only humans have the cognitive (or moral etc.) capacities for valuation[10].

But these categories, on further examination, are more nuanced than they might at first seem. Following Alfred North Whitehead, I take the view that value which is truly divorced from any living system is inert, with little to be said about the underlying reasons for that value, or the conditions for its arising. Conversely,

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[9] In Lockean terms, value here might be considered a primary quality, apparently akin to mass, solidity, extension or atomic structure (Locke, 2017 [1690], p.30) (Dolfsma, 1997). These qualities are inherent to objects regardless of our perception of them. On the subjectivist side, value becomes a secondary quality, i.e. one produced in the mind as a result of perception of the world and its primary qualities. Oft cited secondary qualities include texture, taste or colour (Locke, 2017 [1690], p.30). I do not want to stake too much on this reading of Locke and value however.

[10] What exactly the capacities are for being able to value things is also sometimes equated to the question of which entities possess intrinsic value, insofar as being intrinsically valuable is assumed to be a precondition for being able to instrumentally value things (O’Neill, 1992; Muraca, 2011; Callicott, 1990). Various answers have been given to the question: value as dependent on living things generally – biocentrism (Rolston, 1982a; Stone, 1972)); dependent on humans specifically - anthropocentrism (Hargrove, 1992); dependent on a capacity to experience- pathocentrism (Varner, 2001)); or perhaps dependent on the larger systems living things take part in - ecocentrism (Sandler, 2012, p.243; Muraca, 2011).

as a purely subjective quality, value becomes at worst epiphenomenal, and at best, simply a feature of the relevant (typically human) mind (Whitehead, 1920). Few argue for such extreme subjectivist or objectivist positions, however. That living systems – including those external to the valuable thing - are a key part of the story when discussing value is something recognised in well-developed subjective and objective theories of value, even when discussing intrinsic value (Gilliand, 2021; O'Neill, 1992))[11]. This is not to capitulate to subjectivism: value can have varying degrees and kinds of dependence on and independence from humans and other living systems.

This may represent a tacit 'interactionist consensus' in the theorisation of value, analogous to that found in discussion of gene-environment interaction in philosophy of biology. Just as it is commonly recognised that there are no organismal traits without environment and genes, and that to focus on only environment or genetics is to miss the whole picture (Ferreira Ruiz and Umerez, 2021), so it is increasingly recognised (in some areas of scholarship) that value is often best understood as a relation between entities which may not be simply reduced to the labels *objective* or *subjective* (Stenseke, 2018; Muraca, 2016).

Such a movement is manifest in a turn towards relational understandings of value in the sustainability sciences, itself part of a broader relational movement happening in many different areas (Stenseke, 2018). Here 'relational value' has come to mean a diverse movement which seeks to do several related things:

- Attempting to move beyond the subjective/objective dichotomy when considering value, notably by adopting a processual and relational view of value in ecosystems (Muraca, 2016)
- Moving past the intrinsic/instrumental dichotomy by introducing a new class of values (relational values) which subsumes or co-exists with instrumental and intrinsic value (Muraca, 2011; Stålhammar and Thorén, 2019; Chan, Gould and Pascual, 2019)

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[11] For example those of environmental ethicists J. Baird Callicott (a subjectivist) (Callicott, 1986, pp.142–143), or Holmes Rolston and John O'Neill (objectivists) (O' Neill, 1992; Rolston, 1994; Connor and Kenter, 2019). Railton, an objectivist, takes a similar route, using the analogy of the nutritional content of a vegetable, which may still be indexed to humans, but is not simply produced by the human mind. In the same way, value can depend on a living entity without being subjective (Railton, 1986, pp.9–10). Railton seems to use nutrition as an analogy to value, but I take him to already be talking about a form of value here - nutritional value - given that it contributes to the organism's survival.

- Seeking to understand value as related to what environments *mean* to the relevant agents (Stålhammar and Thorén, 2019; Tadaki, Sinner and Chan, 2017, p.1206)
- Introducing new vocabulary for better describing our value relations with nature, beyond the dominances of economic terminology (Stålhammar and Thorén, 2019; Deplazes-Zemp and Chapman, 2020; Tadaki, Sinner and Chan, 2017, p.1206).

I situate this thesis partly within this movement, but in doing so do not adopt it wholesale. There are more specific aspects of relational value theories which I instead hope to build on:

First, proponents of the relational framework sometimes reserve the label ‘relational’ for forms of value which are specifically relevant to the relations between humans and nature (Himes and Muraca, 2018) – i.e. are anthropocentric - for example defining relational values as ‘preferences, principles and virtues about human-nature relationships’ (Chan, Gould and Pascual, 2019, p.1), or focusing on what ecosystems mean *to people,* rather than just living agents (Tadaki, Sinner and Chan, 2017; Stephens, 2021). Here, I seek to include relationships between non-humans and their environments too, rather than necessitating some human component.

Second, some authors distinguish between the ‘innate relationality of all evaluative processes’ (Himes and Muraca, 2018, p.1), i.e. value which is relational ‘in nature’, and relational values as a subset of this, i.e. denoting values which have relationally-oriented content, such as those concerned with things like kinship, spirituality and identity formation. This latter set of values are termed ‘non-instrumental anthropocentric values’, and are primarily invoked in moral and cultural contexts (Cornick et al., 2019; Stålhammar and Thorén, 2019; Himes and Muraca, 2018). An example is that a preference for seeing birds is relational in origin, whereas a sense of kinship with birds is relational in content (Chan, Gould and Pascual, 2019, p.4). Following Norton and Sanbeg (2020, p.6), I do not employ this distinction. It is the innate relationality of evaluative processes I am interested in here. In doing so I also include values beyond moral and cultural contexts, coupling this with my move to extend relational accounts to include non-anthropocentric values alongside anthropocentric ones.

The view I take on value here is relational in a broad sense, then, meaning that values are something which emerge in a range of relations between living things and their environments. Such values are important parts of the world in their own right, and they are not simply reducible to the subjective or objective (Whitehead, 1920, p.29; Muraca, 2016; Gilliand, 2021; Norton and Sanbeg, 2020). In doing so, I try to avoid the underlying dichotomy between nature and the mind which is set up when distinguishing objective from subjective properties, as well as the conflation of lots of different concepts under the labels objective and subjective (Douglas, 2004b; Cartwright et al., 2022, p.86). For these reasons, I will largely avoid using the terms ‘objective’ and ‘subjective’: they are at once too broad (including a whole range of somewhat distinct considerations under singular labels (Douglas, 2004b)) and too narrow (with a needless focus on mental activity rather than the whole range of interesting ways phenomena may be indexed to living systems). Where I do use them I will try to specify which sub-meanings I am referring to (see e.g. Douglas (2004b); Daston and Galison (1992); and Cartwright et al. (2022) for some disambiguation of these[12]).

Meta-naturalism

A relational view of value also impacts further distinctions downstream from the objective/subjective split. A key area is debates within philosophy of medicine over the nature of illness. Here, normativists are painted as arguing that illness is simply any physiological state which is sufficiently subjectively disvalued, whilst naturalists are taken to completely exclude a role for anything related to value[13] (Kingma, 2014, p.590; Glackin, 2019; Boorse, 1977). Related to this are cognitivist and non-cognitivist approaches to value. A psychological view of value fits nicely with non-cognitivism, which sees value as simply a matter of emotional charge, with no semantic content. On this view, values are not things

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[12] This is not to say that they are not useful terms in other contexts, or to advocate that they are abandoned by others, but just that their use in discussion of value is troublesome enough to warrant avoiding them. For work on abandoning objectivity see Cartwright et al. (2022, p.100)

[13] Except in the sense that they sometimes treat evolutionary processes themselves as providing a natural basis for normativity, and so fulfilling the role played by human value judgements in normativist accounts.

which can be debated or discussed at all, but instead are simply brute assertions of the preferences and whims of the valuer (Putnam, 2002; Ayer, 2001). At the other extreme, values may be seen as simply another kind of, or reducible to, the facts about the world (this may likewise sit well with an objectivist view, but they are not co-dependent). This latter kind of approach leaves no space for the difference between facts and values, and can lead to overly paternalistic judgements about how to live well (Glackin, 2010; Gorski, 2013).

By refusing to oppose nature and values, or to strictly dichotomise facts and values (Putnam, 2002), one opens up possibilities for richer examinations and discussions of value across contexts (Helgesson and Muniesa, 2013). Value is no longer simply a non-cognitive psychological matter, or an objective one for study with just the tools of natural sciences, but is instead intertwined with knowledge, expertise, and socio-ecological context[14]. Discerning value in coral reef systems and science becomes more than just surveying people to examine the contents of their minds. It requires instead an understanding of reefs themselves, the people that study them, the contexts they are valued in, and the lives and livelihoods of the organisms that interact with them. Given the variety of interactions within coral systems which may involve value relations, understanding these will necessarily involve investigation which straddles disciplinary divides, be them objective/subjective, quantitative/qualitative divides or social/natural. Some forms of value may be described seemingly without direct recourse to anything qualitative or subjective, such as the role of nitrogen in tree growth, which may be ascribed a functional value[15] (Brown, Bergstrom and Loomis, 2007, p.343). Others will be linked directly to preferences, wellbeing or consciousness, such as with aesthetic or recreational appreciation. By putting these different senses of value on an equal metaphysical footing (i.e. recognising that they are all in some sense linked to, but not reducible to, a living system), the connections and distinctions between them and the contexts they arise in can be explored.

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[14] This is in contrast to views of value where value is divorced from expertise and is not changed by it, allowing for facts to become value-laden but not values to be fact-laden (Vellend, 2019).

[15] I return to ecological functions later, which form a key point of discussion in this thesis, being very important in understanding coral value in biological, economic and scientific contexts.

By taking a view on value which treats it as not simply psychological, but something instantiated in a wide variety of relations, I adopt a meta-naturalistic approach to the study of value. Here, various features of the world traditionally bracketed off from empirical examination, notably value and the process of science itself, which have often been examined as though separate from the natural world they emerge from, are also considered legitimate targets for empirical examination (Rouse, 2016). Nature, including science, is not anormative, waiting for values to be applied to it, but is run through with value relations (Rouse, 2023b; Putnam, 2002). Science is not a purely factual endeavour which simply describes the world in a single way, but is a process which involves the considerations of perspectives and interests (Kincaid, Dupré and Wylie, 2007; Giere, 2006) and so is deeply intertwined with value considerations, and with the lives of the entities carrying out scientific activity (Rouse, 2016, 2023a). Like Rouse, I offer here an empirical rather than rational reconstruction of science, one which includes values as a core part and treats them as embedded in socio-ecological systems and so amenable to socio-ecological examination (Efstathiou and Myskja, 2019; Rouse, 2023a; Greaves and Read, 2015). Instead of understanding science through the lens of truth or rationality, I include social, ecological, economic and technoscientific interactions which occur between scientists, reefs, and their respective (and intertwined) environments (Rouse, 2023a; b).

The socio-ecology of value and science

Many disciplines have developed ways for discerning value. The position I take here stresses that valuation comes through relations of entities, i.e. that valuation is not an act able to be understood in isolation (Dewey, 1949, p.68). Instead, it is a process which entails interaction of many kinds of entity, some living and some not, across different contexts. This fits with existing sociological, ecological, anthropological and pragmatic approaches to value (e.g. Tsing, 2015, p.122). Throughout this thesis I remain agnostic on what kinds of entities can be included in social relations, including both abiotic and biotic components of the universe. One way to conceptualise such agnosticism is provided by Bruno Latour, who treats the social as including collectives of human, non-human, biotic and abiotic components[16]. These operate in alliances to form and maintain the entities in the universe (Latour, 1993). Social here means simply pertaining to associations (Dolwick, 2009). Again, here, the social at least heavily overlaps with the ecological (ecology being the study of interacting living things).

It is both difficult and unhelpful to distinguish strictly between the social and the ecological, and for that reason I do not attempt to do so in any strict way throughout this thesis. Instead, I take a socio-ecological perspective on reef science and value, including interactions between humans, non-humans, biotic and abiotic phenomena alike, expanding the study of epistemic communities (Knorr-Cetina, 1999) to include a greater role for non-humans. There are several concepts which I have used to think through and articulate this combination of the social and the ecological: socio-ecological metabolic regimes (Landecker, 2013), sets of lifeforms and forms of life (Helmreich, 2009, p.6), entangled life histories (Rouse, 2023a), naturecultural arrangements (Haraway, 2003), and latent commons (Tsing, 2015). Each of these provides a way for thinking about the relation of organisms and the activities they find themselves in, including the complex practices we describe as social. I particularly use the notions of lifeforms and forms of life, the former understood as roughly biological systems in their biological guises, such as organisms and relations between them, and the latter as social, cultural and pragmatic ways of being in the world, typically associated with social contexts (Helmreich, 2009, p.6). I also use the notion of 'living systems' discussed above to avoid over-specifying exactly which chunks of biological matter (and processes) I am including in discussions. I show – as Helmreich argues in his own use of the terms - that lifeforms and forms of life blur into one another in a great many ways (Helmreich, 2009, p.280). Using this blurred socio-ecological lens I offer an account of the epistemology of coral science practice and in doing so answer questions from philosophy and philosophy of science in a richer and more

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[16] Another way is provided by Alfred North Whitehead, who described all entities in both ecological and social terms: physics, he said, is the study of smaller organisms, and biology the study of larger ones; both macroscopic and microscopic entities are organisms, and most are also societies of organisms (Whitehead, 1967, p.105; Smith, 2010, p.8). Here, the ecological and the social are co-extensive, denoting the interaction and co-ordination of sets of entities which have agency in some sense. There are obviously contentious issues about consciousness and agency underlying some of this, which I do not explore further here, exciting as they are.

situated way, such as those about the role of value in science, the inter-relations of different forms of value, what makes for good science, and how a variety of viewpoints can be incorporated into scientific processes, all while recognising the symbiotic and multispecies character of scientific interactions.

Discerning value relations between entities involved in coral reef science is not always a simple task. To do so requires both valuographic techniques and a considerable theoretical background in order to discern and understand the variety of relations at work. A prominent strategy for valuography involves looking for controversies which reveal value clashes (Dussauge, Helgesson and Lee, 2015b). A similar recommendation is found in philosophical discussions of value-ladenness, particularly in terms of assessing how robust scientific assessments are to different perspectives (Alexandrova, 2018; Douglas, 2004a; Funtowicz and Ravetz, 1993). I explore areas of coral science where value clashes are visible, but also where a surprising degree of overlap can be found, for example in the area of ecosystem services and intrinsic value, and also in disagreements over assessment of reef health. These help provide a window into some of the value considerations at work in reef-scientist relations.

Lifeworlds, perception and non-human values

Part of the aim of this thesis is to draw connections between theories around organism-environment interactions, socio-ecological understandings of value, and the epistemology of science. Organisms engage with certain aspects of their surroundings and not others, producing their own environment whilst being produced by it (Lewontin, 2002). Aspects of this environment are then particularly relevant to their survival and reproduction, and are termed their niche (Odling-Smee, Laland and Feldman, 2003). In more experiential terms, the features of an organism’s environment which are perceptually relevant to it have been termed its umwelt, that is, the lifeworld of the organism, those aspects of its environment which have meaning for the organism in some sense (Uexkull, 2010; Yong, 2022). These theories tie nicely into a meta-naturalistic examination of coral reef science, in that they provide conceptual resources for understanding the kind of organism-environment and cross-species interactions occurring within processes related to coral science. They thereby provide opportunities for better understanding the socio-ecological dimensions of coral science and the role of value within this, particularly given the relational view of value I am adopting here. This allows for socio-ecological value theories, such as those related to environmental ethics (e.g. intrinsic and instrumental value), sustainability sciences (e.g. relational value, ecosystem services) and those related to ecological science itself (e.g. ecological functions) to be incorporated into philosophical discussions around the roles of value in science.

By studying organism-environment interactions, it becomes possible to learn more about their perspectives and also our own (Haraway, 1988; Osorio and Cuthill, 2015; Haraway, 2016, p.69). The lifeworlds of organisms are not simply impenetrable bubbles, then, but may be understood, grasped, and compared with our own (Yong, 2022). Various studies have shown that value relations and knowledge production can be fruitfully traced across species boundaries (Tsing, 2015; My Octopus Teacher, 2020), incorporating non-human agents into social and scientific processes (Stephens, 2021; Connor and Kenter, 2019). By treating value as embodied in activities and practices (Dussauge, Helgesson and Lee, 2015a), it is no longer as constrained to the human world.

It might seem strange to say the activities and behaviour of reef organisms and systems involve value, values or valuation, but the theoretical basis of this is no different to many ways of analysing tacit valuation behaviour in humans. Much of economics, for example, relies on choices to reveal implicit value preferences (Parks and Gowdy, 2013). Pragmatist theorists of value have likewise emphasised that value appears anywhere which is beyond the ‘blindly impulsive and mechanically routine’, and where selection and rejection are involved (Dewey, 1949, p.66; Dolfsma, 1997), i.e. when entities discriminate between options and favour one. Studies on how values tacitly shape science itself also do so by looking at the choices of scientists, implicitly working out their value judgements from there too (Dupré, 2007; Douglas, 2000; Vellend, 2019; Elliott, 2022). This is not a simple behaviouristic view on value however, but instead a recognition that mind, world and physiology are intertwined and extended into one another, and so the activity of living systems gives clues as to how things are valuable for them.

Scientists too also refer to value in biological systems, for example in marine bioacoustics, which is concerned with understanding ‘the role of acoustics in the lives of marine animals' (Montgomery and Radford, 2017, p.502)[17], essentially a biosemiotic endeavour of unpicking organism lifeworlds. Similarly, the study of functional value in marine ecosystems, i.e. the degree to which some ecosystem process contributes to a specific habitat, also involves a notion of non-human value (Harborne et al., 2006). Saying that something is valuable to something else, e.g. the presence of algae having value for coral fish to graze on, involves an understanding of the nature of these entities and their relations, but it does not, on the view I take here, commit you to saying that there is a process of conscious valuation here. Fish do not need to think that algae matter in order for algae to be valuable for fish. Describing such a relationship in terms of value is not necessarily to attribute complex psychological or conscious traits to any of the organisms involved, but simply to examine them in terms of the concepts mentioned earlier in this chapter: care, attention, choice, selection, significance and contribution.

Values in science

As with other areas of science, such as molecular bioscience, different forms of value pull on the same processes and entities in different directions (Lee and Helgesson, 2020). What counts as good bioscientific technology, for example, may vary depending on if the priorities of the assessor are objectivity, universality, or reproducibility. Each of these options involves appeals to different values. Variation in modes of valuation may occur even in the same discipline and laboratory (Lee and Helgesson, 2020). This phenomenon is taken to further extremes in coral science, where the stakes are high due to the cocktail of anthropogenic threats corals face. Here, a wide range of valuation processes are discernible, pulling in different directions on the practice and content of coral science. The valuations underlying and shaping coral science are what I explore throughout this thesis, including how they interact with one another and with coral reef itself.

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[17] For example:
"The value of a cue depends on the medium in which it is propagated, the relevance of the information it carries, and the ability of the receiver to detect and interpret it" (Simpson et al., 2010, p.1098). "Signals, by definition, have some biological value to either the sender or the receiver. Biologically produced sound may be inadvertent (of no value to the sender) as in the case of urchin noise, but still provide useful proxy signal for receivers interested in the presence of urchin habitat, such as larval fish looking for a place to settle. Most biologically produced sound, though, will also be of direct value to the sender through a role in either echolocation or intraspecific communication." (Montgomery and Radford, 2017, p.504)

Science-value interactions come in many forms, starting with more seminal notions of underdetermination of theories by evidence (Quine, 1951; Putnam, 2002; Stanford, 2017) and the role of epistemic values such as simplicity in theory choice (Kuhn, 1977)[18]. Since then, more cases of epistemic and non-epistemic values influencing both external and internal aspects of science have emerged, such as when evaluating the risks of accepting or rejecting hypotheses (Douglas, 2016) or when making choices about the construction and application of concepts (Dupré, 2007). Other developments include challenges to the epistemic/non-epistemic distinction (Rooney, 1992), and accounts which show value influencing scientific practices as well as concepts (Lee and Helgesson, 2020). More exotic ways of relating value to science have also been explored, such as treating the scientific laboratory as a site of production of various forms of value (Pinel, 2020).

There are several ways to approach this topic. *Values, value* (or *forms of value),* and *valuing* all have different implications*.* Whilst this may be partly linguistic (these are of course related notions), much of the discussion of value in science has been about *values* as influencing the content and practices of science. Typically this involves ideals of sorts: simplicity, fruitfulness, accuracy, universality on one hand; personal, ethical and social values on the other (Douglas, 2016; Rooney, 1992; Elliott and McKaughan, 2014). *Value*, in contrast, is more often attributed to entities or processes, and as such the immense cultural, economic and ecological value attributed to coral reefs (Costanza et al., 2014). In the context of ecosystems, value is often conceptualised through the frameworks of: use and exchange value; intrinsic and instrumental value; ecosystem services; and newer frameworks such as relational value. *Valuing* and *valuation* has also been used in studies of the way value is tied up in specific practices and processes, for example in laboratory work or food production (Heuts and Mol, 2013; Doganova et al., 2014; Dussauge, Helgesson and Lee, 2015a). Valuing and valuation studies are also often associated with exactly the kind of theoretical basis I want to adopt here, namely the recognition of valuing as a social (or better, socio-ecological) process, and which is not fully captured by explanations which rely on simple

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[18] Very roughly, epistemic values are those which promote the attainment of truth, such as accuracy, consistency, simplicity and fruitfulness (Douglas, 2016). Non-epistemic values are any other form of value, such as values described as ethical, social, personal or religious.

notions of subjectivity or objectivity (Helgesson and Muniesa, 2013). The relationship between these value frameworks on the one hand and values in science on the other is something I explore throughout this thesis.

The coral reef case brings these considerations together nicely. Coral reefs are bearers of immense value which are subjected to intense scientific study. Many forms of value are relevant here: ecological, epistemic, economic, affective and aesthetic, for example. Here I draw more direct connections between these senses of value: value as studied in areas like ecology, economics, sociology, and anthropology; value as attributed to entities in the world; and values as influencing science.

There is also a large literature on value in ecology and conservation, including recognition of the essentially normative nature of conservation, such as its commitment to the value of biodiversity (Soulé, 1985). Relatedly, there have been discussions about the role of concepts like biodiversity as meeting places for value and scientific judgment (Sarkar, 2019). Values are also often noted as operating in areas such as health and wellbeing (Kingma, 2007; Alexandrova, 2018)[19], resulting in concepts and claims in these areas being considered ‘thick’ or ‘mixed’ (Putnam, 2002; Alexandrova, 2018). As such, it will not be surprising to philosophers versed in these areas that reef science too is value-laden. What will hopefully be of interest here is a more detailed understanding of the epistemology of coral reef science and its practices, along with a richer understanding of the nature of value in scientific and organism-environment interactions, and an exploration of the connections between these two topics. Whilst it has previously been suggested that non-epistemic value should not directly influence the characterisation and interpretation of evidence (e.g. Douglas, 2016), and that attributing value to the objects of study of ecology (such as specific organisms, species, functions or structures) can have a pernicious influence on ecological science, subtly skewing results and how they are presented (Vellend, 2019), I argue here that some value attributions are also necessary for coral reef science to be relevant to the lives of the various organisms connected to reef systems, including humans. And, as I will argue in the following chapters, given that science is performed by lifeforms and

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[19] Although even here a role for value is sometimes still denied, such as in purely naturalist accounts of disease (Powell and Scarffe, 2019)

embedded in socio-ecological forms of life, it is unavoidably value-laden in several different ways.

Methodology

Disciplinary positioning

This thesis is the result of a project which sits at the interface of philosophy of science in practice (PSP) and Science and Technology Studies (STS). Philosophy of science more generally is interested in questions around the nature of science, and has particularly focused on the relation between scientific theories and the world, along with related topics such as the nature of truth, observation, and objectivity, the reality (or not) of the entities postulated by scientists, and the roles played by values in science. PSP builds on this in several ways. First, it takes a focus on a broader range of scientific activities beyond theorisation. As well as examining scientific theories, PSP also typically involves a focus on other processes and products of science, such as models, techniques, goals, equipment, infrastructure, communities, and systems of practices (Boon, 2017; Ankeny and Leonelli, 2016). Whilst philosophy of science is often interested in theories and how they relate to the world, PSP also entails considering also the scientist, as a knowledge producer, and the practices they engage in as well as the theories they produce about the world (Ankeny, Chang and Boumans, 2011).

A related shift in focus is an increased attention to both material and conceptual features of science, something which brings PSP into close connection with STS and science studies more broadly. These areas are all similarly interested in interactions between scientists, technology and society (and the environment), and sociologists, philosopher, anthropologists and historians of science have often investigated these in dialogue with one another. PSP takes on board the need to include more than just conceptual and theoretical features of science (a point also made by other traditions in philosophy) but also retains a strong connection to debates and themes within philosophy of science (Boon, 2017; Ankeny, Chang and Boumans, 2011), for example the role of values in scientific processes, or questions around how scientific disciplines are evaluated (two topics I explore here).

PSP furthermore involves a keen focus on the situated nature of scientific knowledge production, be that through attention to historical contingency, institutional and social context, disciplinary differences, or normative factors, which may all shape science in ways beyond those explored in traditional philosophy of science (Rouse, 2023b, p.4). Normative factors such as values and goals are particularly relevant to this thesis. PSP scholars have been keen to explore how such factors shape science, with particular attention to those often considered external to science (Ankeny, Chang and Boumans, 2011).

This thesis, following in this tradition, studies the content, practices and living systems involved in coral science. In exploring this, I offer a situated account of a cluster of scientific processes. I investigate how coral scientists conceive of the value of reefs (both explicitly and implicitly); the activities they engage in as a part of coral science, including the theories and concepts underlying these; how these processes are socio-ecologically embedded, in terms of being shaped by and shaping their environments; and how this can all help with understanding the nature of value in complex socio-ecological and epistemic systems.

Given the shift in focus embodied by PSP, practitioners use a wide range of techniques in order to better understand scientific practices and repertoires (Poliseli and Russo, 2022, p.7). This is another sense in which PSP and STS are closely related. Following others in PSP and science studies more broadly, I conducted an empirical analysis of the relevant scientific literature (e.g. Latour, 1993), followed by a series of interviews with coral scientists (e.g. Braverman, 2018). I aimed to improve understanding of the nature of coral science - particularly coral ecology - but also produce insights about scientific processes and valuation more broadly, including sciences faced with similar ecological and existential challenges as coral science. In doing so, I hope to provide situated answers to questions asked in various areas of philosophy, including: What makes for good science? What are the goals of science? How can we understand ecosystem health? How do intrinsic and instrumental value relate? I also draw connections with science studies more broadly and approach issues of interest to science studies scholars, such as those around flourishing, agency, value, and knowledge production in multispecies systems, or around the relations between scientists and their material environments. Much of this thesis is to do with human and non-human organism relations. There is a large relevant literature on this topic in STS and animal studies – particularly around the idea of care - and whilst I draw on a small amount of it, integrating it more thoroughly was beyond the scope of this (already very interdisciplinary) thesis, and so this is a task for subsequent work I plan to do on this topic.

I also sought to answer questions which have a strong bearing on scientific practice (Boumans and Leonelli, 2013), with the aim of producing both scientific and philosophical insights (Lewens, 2020; Zach, 2023), particularly questions related to how baselines can be both normative and reliable, how reef health can be discerned given huge variety in reef systems, and how different value frameworks can be used simultaneously without contradiction.

Typically PSP practitioners might engage in more in-person examination of practices, such as ethnography, which was originally planned as part of the project, but due to the historical and socio-ecological positioning of this project (conducted during what has so far been the height of the Covid-19 pandemic) this was not possible. Despite the cancellation of all formal in-person ethnographic methods, I did continue learning to scuba dive and diving recreationally, something which has formed an important if indirect part in my thinking around this thesis and related topics[20]. Taking part in a key mode of engagement with the natural world for many reef scientists helped me get a better understanding of coral science practices whilst ethnographic methods were not available. It has still been possible, through interviews and close analysis of scientific texts, to dig deeper into the activities which make up coral science. I now explore in more detail how I went about employing these techniques to this end.

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[20] Snorkelling and scuba diving have been recognised by others as an ethnographic method and as an object of study for anthropologists (Bright and Kimmey, 2021; Bubandt, 2022). This is also a part of PSP, whereby engaging in the practices of the sciences being studied can help better understand them, in part due to the emphasis of the importance of tacit knowledge in science, which is often found in PSP work.

Literature analysis and interview preparation

A core part of this project involved reading and analysing scientific literature relating to coral reefs, particularly ecological research, but also small amounts of microbial and geological research where they were relevant to ecological topics (primarily discussed in chapter two). As mentioned in the introduction, coral science also has many features which make it distinctive, and so many of the conclusions drawn here will not apply to other areas of science. The scope of the claims I make is also limited by the small and relatively homogenous sample of interviews taken (discussed in more detail below). As such, the insights presented here may also not apply to other areas of coral science, for example more geologically focused reef study was not explored as much as the biological and ecological aspects, and microscopic scales were also relatively underexamined compared to macroscopic ones. That said, aspects of this thesis have relevance beyond (ecologically-focused) coral science, something I return to in the conclusion.

Analysis of scientific literature was used to develop relevant background knowledge about coral reefs, but also to look for topics which would provide a way into understanding the role and nature of value in coral science. I closely read papers from marine ecological and coral science journals, including those from scientists at my own institution, and those related to the topics which seemed of most relevance to the project. These topics were continually identified as the project unfolded, but revolved initially around ecological functions and services (Brandl et al., 2019; Moberg and Folke, 1999), which quickly became a key focus of my literature analysis, and an obvious candidate for further study in interviews. I also became interested in the use of specific techniques for assessing reef health, particularly bioacoustic methods, visual reef composition surveys and carbonate budgets (Gordon et al., 2018; Jokiel et al., 2015; Perry, Spencer and Kench, 2008). Related to this was a body of literature on phase shifts in reef ecology (for example, domination of a reef by algae, sponges or urchins, rather than coral (Hughes et al., 1994; Fulton et al., 2019)) and contentions related to this (about the reliability and desirability of such techniques as tools for assessing health) (Bruno et al., 2014; Vroom, 2011; Vroom et al., 2006; Woodhead et al., 2019). I also focused on papers about interventions to save coral reefs, particularly biobanking, assisted evolution and assisted migration, along with other techniques for improving the likelihood of coral survival in the face of anthropogenic threats (NASEM, 2019). Each of these topics offered a window into understanding reefs as not simply objects of scientific study but as sets of entities and processes which were valued by scientists.

From this reading of the literature, a key theme which I chose to focus on was ecological baselines and alternative ecological arrangements in reef science, which offered intriguing philosophical questions as well as a clear role for value. Based on this I drafted an article on the role of value in ascribing the labels ‘regeneration’ and ‘degradation’ to process on reefs, which was published in the journal *Synthese* as a stand-alone paper. This was influenced by two events I attended at Woods Hole’s Marine Biology Laboratory on the nature of regeneration across scales in living systems, held as part of the annual MBL History of Biology Seminars. The paper went on to form the basis for the first two chapters of the thesis, on baselines and health in coral reef systems. I eventually refocused from regeneration to reef health and baselines given the prevalence of these terms in coral science literature[21]. The term health is commonly applied to ecosystems in coral reef science, for example see Lange, Perry and Alvarez-Filip (2020) or Knowlton and Jackson (2008), something which is linked to the adoption of biomedical repertoires by coral scientists in recent decades (Ankeny and Leonelli, 2019). As such, the use of this concept seemed like an obvious choice for framing discussions around the desirability of different reef systems. Baselines were also often invoked in both coral science work and work on coral science and other areas of ecology, often fraught with anxiety and debate (Bruno, 2013; Sandin et al., 2008; Eddy, Cheung and Bruno,

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[21] For those adverse to the idea of ecological health, the term can be fairly well substituted throughout this thesis with the idea of functioning or desirability. Each has slightly different implications, but broadly speaking are used to refer to the same thing. Desirability might invoke a kind of narrow anthropocentrism to some readers – i.e. a lack of concern for things which do not satisfy immediate human desires (Lackey, 2001) – but as I show in later chapters this kind of narrow anthropocentrism is not present amongst the scientists I have interviewed or whose work I have read. In coral science literature the terms healthy, desirable and functioning are often used interchangeably, see for example Leinfelder et al. (2012); Bellwood et al. (2004, pp.827–828); Brandl et al. (2019, p.445). There is still some detectable unease with the term health, for example use of quotation marks around the word health in paper titles, as in ‘Carbonate budgets as indicators of functional reef “health”…’ (Lange, Perry and Alvarez-Filip, 2020), or in discussions with one interviewee, a socio-ecologist, who explicitly mentioned unease with it, but broadly speaking the term itself was not questioned during interviews.

2018; Campbell et al., 2009; Braverman, 2020; Ureta, Lekan and von Hardenberg, 2020).

I used interviews to get a better understanding of what was happening in discussions around baselines and health in coral science by including an interview question specifically about coral reef health in the interviews, as well as a more indirect question about perceptions of changes to reefs:

- how do we know when a reef is healthy?
- What are the biggest changes you've seen happening to reefs in your career?

The close reading of scientific literature also drove me to focus on several other topics when preparing for interviews. To arrive at these questions, I drafted a large list of potential questions, which I whittled down to develop the interview protocol (a copy of this is appended to the thesis). Functions and services seemed obvious sites for understanding how scientists think about reef value. Functions were invoked very commonly and applied to many different processes, as well as being subject to conceptual analysis by coral scientists themselves (Bellwood et al., 2019). Services were also very commonly invoked, and as a topic which is often controversial, offered an interesting route into understanding how coral scientists think about their relations to reef systems. This led me to ask specifically about both of these topics:

- What are the key functions of coral systems?
- Do you use the term ecosystem services in your work, and why?
- Which aspects of coral reefs would be hardest to replace if they suddenly disappeared? What would be the biggest changes to our lives?

Through attending to coral science texts, it became obvious that there were several entrenched ways to discuss coral value when the topic arose. Statistics about the monetary value of service provision, about the percentage of marine biodiversity supported by reefs, or about numbers of people sustained by reef-derived protein were very common. I wanted to avoid focusing on these entrenched mobiles and so sought to include questions about value which were phrased in broader or less obvious ways:

- How did you end up studying corals?

- What aspects of coral reefs do you study? What led you to work on those aspects?
- What kinds of coral reefs do you study? (is there a specific reef, area or reef organism you study?) What interests you about these?
- Is there anything you wish more people knew about coral reefs?
- Can you think of any moment where learning something about coral changed your appreciation of them or of the living world generally?

A key part of this was to ask about how they got involved in coral science and the focus of their work, but also to provide opportunities to reflect on reefs, what people think about them generally, and if they had particularly memorable moments interacting with corals or reefs. Finally, I was also interested, from the literature, on the kind of methods being used to save corals and reefs, as well as the ways in which corals had contributed to science. Papers quite commonly proclaimed the need for new methods to save reefs, such as biobanking or modifications to their biology. In early interviews I asked:

- how do you model coral reef systems?

But after being met with some confusion in the first few interviews, I shifted to a broader question:

- What tools or systems do you use to understand coral? (Sometimes followed by 'Do you use any models, or model organisms?')

This broader question elicited richer information and discussion about coral science methods, which allowed me to explore a bit more the practices coral scientists engaged in and their relation to the value of the reef system. I also asked:

- What are the biggest scientific insights to come out of studying corals?

The aim here was to build on some of the elusions in the literature to the epistemic roles of corals in science, for example as entities which tell us about past or future climate[22], or about symbiosis and its collapse, or about ageing, cancer or other topics (Roberts et al., 2009a, chap.7; Haas et al., 2016;

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[22] 'Their story is that of the planet, for the earliest reefs were made by the first life of all, and the demise of their descendants, so often foretold, may mark the end of existence as we know it' (Jones, 2007, p.56)

Dubinsky and Stambler, 2011; Blackall, Wilson and van Oppen, 2015; Bythell, Brown and Kirkwood, 2018). I also wanted to further explore the kind of interventions being conducted to save coral, which seemed a clear choice for wanting to understand how knowledge and value are coproduced in coral science. In earlier interviews I asked:

- Do you participate in any coral biobanking projects?

Along with a string of planned follow ups about what biobanks should prioritise, if they are a good idea or not, etc. This was driven by high-profile articles about such attempts to produce coral biobanks (Zoccola et al., 2020). Unfortunately, none of the first wave of participants were involved in such projects, and so the question was not a very useful one. Instead, I shifted to a broader topic which was more relevant to a wide range of scientists, and often near the forefront of their minds:

- Do you participate in any restoration projects?

It was clear from the literature both within and on coral science that restoration was at least somewhat controversial in this context, which offered an entry point for discussing what coral scientists thought they should and shouldn't be doing as coral scientists (Braverman, 2018; Anthony et al., 2017).

Interviews

The interviews I refer to in this thesis were conducted via Zoom with 26 coral scientists throughout 2021. 21 of these were marine ecologists, with the others including a taxonomist, socio-ecologist, geologist, marine physiologist, and a proteomicist. Of the ecologists most were interested primarily in macroscopic organisms and interactions (only 4 had explicitly microbial and molecular interests).

A range of considerations impacted who I contacted for interviews. Relevant factors in my search were career stage (where I wanted to ensure a good mix), focus of research (where I wanted a mixture of locations of study), institute (again, where I did not want one institute to dominate), and disciplinary positioning (where I focused primarily on ecologists, to avoid getting too small of a sample of any one discipline). I chose also to include 5 cold water coral scientists[23].

A key consideration for interviews was access. Whilst I was lucky in the sense that Zoom meetings became much more normal for many people during the pandemic, I found that personal and institutional connections still made it more likely that potential participants would agree to be involved, and so used snowball sampling and recommendations from participants as to who else might be receptive to participating. I produced a spreadsheet of target interviewees across a range of institutes. These were primarily UK based, for ease of access and to capitalise on snowballing networks. I focused on people who work extensively on coral reefs, avoiding moving out into those working on peripheral issues (e.g. many people work on fish ecology relevant to reef contexts, but without an explicit reef focus). This resulted in three main clusters in terms of institutional affiliation: 5 people directly associated with Exeter, 6 from another UK university and a further 3 from another UK university. All other participants were from other universities (mostly in the UK), except from one working at an NGO and another at a museum.

At first I tried to factor in the geographical location of reefs worked on by scientists, but this proved difficult to do given that many scientists had worked in lots of different contexts throughout their careers. Instead, I aimed for a mix of locations, and ensured that Australian reef science did not dominate the sample (given that it is particularly well funded and internationally prominent). The aim here was not to represent all reefs, or do a stratified sample, but to simply ensure the discourse was not dominated by the Great Barrier Reef or other more well-studied tropical systems, and allow for potential surprises from other locations, as well as capturing the socio-ecological dynamics of scientific practices beyond simply those of one country or reef system.

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[23] For the purposes of this thesis the differences between cold and warm water coral science are usually not large enough to require separate discussions. There are still some interesting differences however: cold water reefs are less systematically threatened by climate change (although acidification could cause problems for their ability to maintain their structures in the future) and are more threatened by localised trawling. So the ecological underpinnings of cold water reef science are different. Similarly, their connections with humans – e.g. economically and culturally - are less direct and less well-defined. I explore these further in the thesis where relevant.

Before interviews I analysed scientific articles produced by interviewees (in some cases they sent me documents to read before and/or after interviews), as well as reading about their academic backgrounds and examining their online profiles. I used these to confirm they were appropriate for interview, and to identify any specific topics which may be relevant to discussions, and more broadly to understanding the role of value in coral reef science, for example some interviewees were involved with specific projects, which I made a note to discuss in interviews if they looked relevant. No one was excluded from interview based on this process, but specific participants were contacted because of work particularly well connected to the certain topics.

Interviews were semi-structured, with seven core questions being put to most of the participants, along with extra questions depending on the circumstances. The aim was not to explicitly ask ‘what is valuable about coral?’ but to tease this out in conversation, in order to avoid participants answering in the narrow, rehearsed and predefined terms that coral value is already discussed in[24].

In some cases, where there was sufficient time, I also asked explicitly about whether people engaged in recreational marine activities (this often came up naturally at the start of interviews anyway), and whether their aesthetic appreciation of reefs had changed since becoming a coral scientist. I also allowed interviews to meander onto different topics where these seemed they might be relevant.

Transcription and Analysis

I wrote brief notes during interviews which I wrote up immediately after, along with a narrative description of the interview and main themes which occurred to me during it, producing a set of notes for each participant. I transcribed data with the help of AI transcribing software, which I then corrected whilst listening to the audio. While I was editing transcripts I added to the notes for each participant, and thought about possible themes for analysis. I had some idea of key themes already - e.g. functions and ecosystem services - which informed the questions, allowing for a deeper analysis than the literature could provide.

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[24] Whilst I am interested in these well-rehearsed ways of articulating reef value, I wanted to interviewees to approach reef value in a less pre-prepared manner, and open up space for exploration of less appreciated forms of reef value, along with how these relate to the practice of reef science.

The other themes around which the chapters are built developed more as I was interviewing, transcribing and analysing.

Drawing together the notes from interviewing and transcribing, the notes and written work from the literature review and theoretical components, I began to thematically analyse the results of the interviews. To do this I used NVivo 1.7's coding function, importing word documents of the transcripts into the program to be analysed. During this process I also made documents of overall interesting themes from notes from interviews, transcribing, and coding, and put these all into a document, grouping and periodically reviewing them to look for key topics to structure chapters around.

Whilst I had a longer list of possible themes, I whittled these down in order to keep themes to a minimum. I started the analysis using just a handful of codes, and focused on each theme in term, including going back and re-examining the data during the writing of each chapter, sometimes adding more data to the theme. I conducted thematic analysis (Riger and Sigurvinsdottir, 2016) on the topics of baselines, bioacoustics, epistemic value, functions and services, and niche construction. Aspects of these developed during analysis, for example niche construction was a later arrival inspired by readings of the literature and discussions during interviews.

Once I had produced a well-developed database of quotes for a theme, I read through quotes, listened back to key interviews, and began to write these into chapters involving data. Some of the chapters, such as the health and baselines chapters, I rewrote from earlier writing, but modified in light of the interview data. Interview data was used to support arguments across several topics: baselining, reef health, intrinsic and instrumental value, non-human value, socio-ecological views of reef science. These chapters were then developed in concert with one another to produce the overall thesis.

Data presentation

A recurring question was how much to clean the data. I was mindful of the trade-off between making quotes easy to read and making sure the data conveyed things like tone. I have included filler and repeated words where they considerably impacted tone and where tone was important to the topic (for example when showing particular uncertainty). I removed sections from quotes if these were not relevant to the topic being discussed, which I marked with an elision symbol ‘…’. I corrected grammar where the meaning of the sentence was otherwise unclear. In terms of non-linguistic expressions, I added only a [laughs] tag, and only then when it seemed particularly important to the tone of the quote. In some cases extra words or context are also added in square brackets to improve intelligibility. Quotes were appended with a numerical pseudonym to ensure it was clear which participant was speaking without compromising their identity, and are marked in this thesis with a quote number for reference throughout the text.

Ethics

After reformulation in light of the Covid-19 pandemic, which disrupted original in-person plans, the primary ethical considerations in this revised plan were to do with data protection and anonymity. Interviews were to be conducted entirely over Zoom and recorded, transcribed and analysed. Participants were given choices about: whether they would like to be recorded (audio, video, both, neither); whether they would like interview data, publications and open access data to be pseudonymised; and whether they would like their transcript to be made available as open access data. Only two participants requested pseudonymisation, although a further two requested to see publications before anything was attributed to them. In the end I made the decision to keep participants all pseudonymised within the thesis, as this was much simpler and did not impede the quality of the data. Data was stored in compliance with GDPR, and participants given the right to withdraw before data is published. Consent for interviews, as well as data preferences, was obtained before interviews via a digital consent and information form, and participants given plenty of time to ask questions before and after the interview.

There were other ethical considerations too: I am mindful of ensuring quotes and data cannot be easily misused for nefarious ends, such as by fossil fuel companies in denial of climate change; I am also keen to ensure that particularly early career researchers do not suffer professionally as a result of taking part in the interviews. A particularly salient issue within coral science is the effectiveness of active restoration versus traditional conservation methods. I have made sure not to stoke any extra controversy here, e.g. by removing mention of specific locations (when irrelevant) in discussions around this topic.

Chapter 1 - Beyond shifts: Sources of variation in the baselining process

> 'The sea there is swarming with fish which can be taken not only with the net but in baskets let down with a stone … These same English … say that they could bring so many fish that this kingdom would have no further need of Iceland'.
>
> Milan's envoy in London, 1497, reporting on John Cabot's return from North America (Kurlanksy, 1999, p.49)

Abstract

Ecological baselines are reference states used to assess changes to real-world ecosystems and determine whether they are healthy or not (Ureta, Lekan and von Hardenberg, 2020). Coral science, amongst other disciplines, is thought to suffer from a problem related to baselines called shifting baseline syndrome. This is a condition where the personal experience of scientists – linked, for instance, to their age and time spent in ecosystems - may cause them to employ different baselines, and so judge ecosystems in very different ways (Pauly, 1995). Despite high awareness of this problem amongst coral scientists, empirical evidence for the existence of the syndrome generally, and specifically within coral science, is scant (Papworth, Rist and Coad, 2009; Muldrow, Parsons and Jonas, 2020). How can this phenomenon be both widely acknowledged as a problem and yet hard to detect? Using interview data, and tools and concepts from philosophy of science and social studies of science, I reframe and try to explain this problem. By considering shifting baselines as related to a more general problem common to many other areas of science, and indeed outside of it, rather than a psychological one linked solely to age or quantity of experience, it can be reframed as the following question: how does variation enter into the process of baselining, and when is this variation legitimate? After this reframing, I argue that within a given baseline, there are multiple levels at which variation can occur, focusing here on ecological, methodological, theoretical, and affective levels. This has implications for how differences in baselines are assessed and detected, which will likely require a suite of mixed methods, notably including qualitative studies of how scientists perceive the health of ecosystems. It also gestures towards a more pragmatic question to ask related to baselines: not 'is this the correct baseline?' but 'is this a reasonable baseline?'. This analysis points to the more fundamental problem

which I deal with in the next chapter: when is variation in a baseline considered legitimate? This question then guides the rest of the thesis, which explores the nature and role of values in a range of scientific practices, and the socio-ecological significance of these practices.

1. Introduction – baselines, shifts and syndromes

In a 2009 paper 'Beyond baselines: Rethinking priorities for ocean conservation', Campbell et al. suggest moving beyond, or at least expanding discussion of, ecological baselines, so as to overcome some of the conceptual problems afflicting the notion of shifting baseline syndrome (Campbell et al., 2009). Shifting baseline syndrome is a key site for understanding science-value interactions, and also a topic particularly relevant to coral reef science (Braverman, 2020), as such, I use it as the starting point for this thesis.

1.1 What is a baseline?

A baseline is a tool used for judging the state of an ecosystem, which works by offering a comparison state depicting how the ecosystem ought to appear (Gillson, Ladle and Ara, 2011, p.38). Baselines comprise a set of observable characteristics, relative to an area and a time, which are taken to be representative of some desirable state of an ecosystem (Jones, 2021). Desirable states may be described in different terms, such as healthy, pristine or functioning (or simply as desirable[25]), each of these terms having different possible implications, but broadly implying a similar positive assessment. These states are the yardstick by which changes to ecosystems are judged as positive or negative, allowing benign variation to be distinguished from damaging cases (Ureta, Lekan and von Hardenberg, 2020).

1.2 What is shifting baseline syndrome?

Baselines pose some interesting problems. They are often described as static representations of systems in flux, which causes problems for understanding change (Braverman, 2020). They are also a key part of an infamous problem in ecology – often phrased in medical terms as a syndrome - thought to afflict ecologists generally and coral scientists specifically: 'shifting baseline

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[25] E.g. Leinfelder et al. (2012)

syndrome' (hereafter SBS). The term 'shifting baseline syndrome' first arose in a 1995 article by marine scientist Daniel Pauly, although 'generational amnesia' - loss of information about the desirable state of an ecosystem between generations of people - was discussed slightly before this in the context of children's perception of the environment (Kahn and Friedman, 1995). Here is Pauly's initial characterisation of SBS:

> 'Essentially, this syndrome has arisen because each generation of fisheries scientists accepts as a baseline the stock size and species composition that occurred at the beginning of their careers, and uses this to evaluate changes. When the next generation starts its career, the stocks have further declined, but it is the stocks at that time that serve as a new baseline' (Pauly, 1995, p.430).'

The premise of the problem, then, is that people employ baselines which depend on their personal experience, that is, they use their past memories of ecosystems to help them judge how healthy a target ecosystem is (Kahn Jr., 2002; Papworth, Rist and Coad, 2009). Because reefs are increasingly degraded, and increasingly morphing into new ecological arrangements (Knowlton, 2001; Graham et al., 2014), older scientists will have different experiences on reefs to younger ones[26]. Older scientists, the story goes, will have encountered healthier reefs early in their careers, and so will see modern reefs as more degraded. Younger or newer scientists will have experienced such reefs in more degraded states generally, and in some cases may assume they are healthy. As such, perceptions and characterisations of reef health will differ depending on the personal characteristics of the observer, calling into question the validity of environmental assessments, particularly in young scientists, who may be too tolerant of degradation (Pauly, 1995; Muldrow, Parsons and Jonas, 2020; Papworth, Rist and Coad, 2009). The problem is popularly recognised, including amongst ecologists generally, and coral scientists specifically, as I show in the next section.

The use of medical terminology ('syndrome') to describe this problem might seem strange, but fits with the influence of biomedical approaches on recent coral reef science (Ankeny and Leonelli, 2019). Over the last few decades some coral scientists have adopted and promoted institutional and scientific practices copied from biomedicine in order to try and facilitate effective global responses

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[26] Note that this doesn't only apply to scientists, but to any observer which regularly interacts with systems which change (including non-human observers). I focus on scientists and ecosystems here though.

to the threats facing coral reefs, both in terms of disease and climate change[27]. As such, the use of medical terminology to describe the problem of shifting baselines fits with other approaches in coral science (and perhaps marine science more broadly), such as a focus on -omics technologies, on the role of microbes and disease within corals, and the production of shared standardised metrics and databases for assessing and comparing reef health globally (Ankeny and Leonelli, 2019). I return to the ‘syndrome’ label later when discussing how the problem can be reframed to relate to a broader class of problems affecting science and human judgement generally.

2. The puzzle

Anxiety around the employment of appropriate baselines has long been a feature of ecology, marine science, and coral science in particular, particularly because the quantity and quality of historical data about the state of underwater environments is lower than that for terrestrial cases, with the sea only becoming properly accessible to humans in the last several decades with the advent of widespread sub-aqua technology (Pauly, 1995; Braverman, 2020). The puzzle around SBS is that despite this widespread anxiety about shifting baselines, evidence for its existence and impact on coral science is slim. To demonstrate and resolve this apparent inconsistency, I will draw on data and concepts from a range of sources: interviews I conducted with coral scientists, literature from coral science and literature about shifting baselines, and ideas from the philosophy of science about the nature of measurement and data. The two most relevant interview questions I will draw on here are ‘How do we know when a reef is healthy?’ and ‘have you seen any major changes to reefs over your lifetime?’, although other parts of interviews are also relevant. This also helps give a deeper sense in what is involved when scientists baseline their environments and make judgements about, and comparisons across them. I hope, by the end of this chapter and more broadly this thesis, to both demonstrate and argue for the usefulness of qualitative and philosophical study of coral reef science, including specifically the issue of how to produce baselines for reef systems (and likewise for other areas of science where baselines are involved).

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[27] I return to this shift in the way coral science works in the final chapter of the thesis.

2.1 Case studies

To illustrate my arguments, I will draw on three particularly illustrative examples from coral science. Each is a set of characteristics focused on in assessments of reef health: first, the relative proportion of algal and coral cover of a reef, representing the degree to which a reef is degraded. The idea here is that although reefs normally have a mixture of both algae and coral covering their surface, high percentages of coral cover indicate a healthy reef, whereas high algal cover smothers other aspects of the reef and represents a degraded state. Participants articulated this framework clearly when asked about how to judge reef health:

Quote 1

> ‘So there are reefs, and parts of reefs that are not coral dominated naturally, but you know, in general, when you look at a reef, we tend to use coral cover as the as the main indicator of how healthy a reef system actually is.’ 1010

Quote 2

> ‘a healthy reef is … there are few fleshy algae, and there are very few thready filamentous algae that are growing, because those are … outcompeted by healthy corals and the fish … And the corals are... heavily covering the landscape. So greater than 50% of what you look down at is, is healthy living coral. So when you get coral bleaching, you know, you have white corals, at least at the beginning, when they're still alive. But then ultimately, they die and they're overtaken, the architecture of the reef is overtaken with this filamentous algae. You might in the short term, still have the fish, but ultimately, they're going to leave and look for other healthier spots’. 1026

There are strong methodological reasons to employ this framework in the baselining process. Coral and algal cover can be easy to discern with the eye (having different visual appearances, notably colour), and can be characterised through well-established methods such as the use of transects for surveys. (A transect is a grid overlaid on a pre-defined area of reef, and the proportions of the grid filled with different organisms are counted, to provide a quantitative measure of the cover of different organisms on the reef (Jokiel et al., 2015).) Along with the stark visual effects of bleaching (which turns reefs from a brownish colour to a pale white, whilst algal takeovers turn them greenish), this allows for a suite of visual methods to help characterise ecosystem health in a fairly standardised way[28] (Braverman, 2020). Note that this is not simply one measurement practice, but a set of related practices, involving varying degrees of computerisation and automation. Whilst these practices focus on the same thing, different versions have different virtues and vices, for example may be more reliable, expensive, work at greater scales, capture different organisms more readily, or require more training to perform (Jokiel et al., 2015). The same is true of other sets of metrics included here, which are all groups of practices which focus on a set of related characteristics. There are debates to be had about the applicability and validity of this particular set of approaches (Vroom, 2011; Vroom et al., 2006; Bruno et al., 2014), but they are not to be had here: what matters at the moment is simply that this is a toolset frequently used to establish baselines on reefs, providing fairly simple characteristics and associated metrics for assessing reef health. Like other cases of ecological baselining, coral scientists must necessarily focus down on specific variables for pragmatic reasons (Ureta, Lekan and von Hardenberg, 2020), and like model systems elsewhere in science, baselines must make abstractions and generalisations in order to be useful (Potochnik, 2017)[29].

There are other reef characteristics which may be focused on too. A second option for assessing reef health are carbonate budgets, which are dynamic models of a reef which represent the rate at which the stone (carbonate) structure of the coral reef - i.e. the bulk of the reef itself - is being eroded or growing. They do this by factoring in the actions of biological and non-biological forces which build up or break down the reef, for example parrotfish which bite chunks out of the reef, or coral and algae which lay down and cement the limestone structure. This can be done through surveys of the prevalence of biological organisms, or through geological and hydrochemical methods (Lange, Perry and Alvarez-Filip, 2020). The overall direction of change of the reef is the net carbonate budget (Lange, Perry and Alvarez-Filip, 2020). Generally

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[28] Note that it is not quite as simple as algae vs coral. In the full version of this quote, the participant mentions other forms of algae which are to be expected in higher proportions on a healthy reef. But the fleshy macroalgae they mention here are still associated with degradation.
[29] The exact relation between models and baselines is something I intend to explore further in later work. Whilst the baselining processes certainly seems to involve idealisation, just as model systems do, it is not simply a case of modelling: there are extra considerations involved, particularly related to the ‘reference state’ role that the baselines play in depicting how systems ought to operate, rather than just helping understand how they do operate. As I argue in the final chapter, the idealisation is often for socio-ecological reasons, rather than just for e.g. producing understanding.

speaking, a positive or neutral carbonate budget is associated with health, because it means the reef is being maintained or growing, whilst a negative budget means the reef will not be able to sustain itself as a structure into the future, eventually eroding to the point of collapsing or losing key structural complexity (Lange, Perry and Alvarez-Filip, 2020). Again, this provides a set of measurements and metrics which can be used to judge distance from a baseline state:

Quote 3

> ‘Traditionally, people just looked at coral cover and algae cover. But in recent years, it has been more and more obvious that these status variables are not good enough to describe if the reef is healthy, will it be in the future, so we're looking more for functional indicators, and reef budgets is just one of that because it gives you an indication about the structural complexity in the reef and about the growth potential of the reef.’ 1001

Finally, I also draw on a third set of examples from reef bioacoustics, whereby the audio signatures of reef ecosystems are measured. By doing so, the biodiversity of the reef, as well as other ecological variables such as the presence and abundance of individual species, can be discerned. Several specific metrics can be employed which take into account the loudness, complexity, richness and other qualities of the noise, including in ways which are more faithful to the hearing capacities of local organisms (Nedelec et al., 2016; Gordon et al., 2018, p.2) . This provides another set of characteristics and associated metrics which can be used to judge how healthy a reef is compared to its baseline state:

Quote 4

> “the reefs are chocka full of animals that do produce sound. So snapping shrimp dominate the soundscape. And then you've got many invertebrates, the scraping of sea urchins, it's called stridulation, where lobsters rub their antennae together and create a vibratory sound, like a rasping sound, and then lots of different fish species all vocalizing. Say the community on a reef is very noisy” 1002

Whilst in some cases they can detect the noises of specific identifiable species, they also use the noises to study the reef as a whole:

Quote 5

> “[often] we’re just sort of describing the soundscape as a whole, admitting that we don't know what makes all the noises, but then we can still tell you stuff about the diversity of that soundscape. The complexity, how it varies in time, where it's louder, where it's quieter, what bits of the frequency windows are being most used, and all that.” 1003.

By detecting these sounds, coral scientists can:

Quote 6

> “study the health of a coral reef … whether that health is changing … because the reef is degrading, through environmental impacts, human impacts, climate change type impacts, or because it's improving … because we're managing it” 1002

I also explore these bioacoustic methods further later in the thesis, and the algae case further in the next chapter. For now, it is enough to introduce these three sets of characteristics and metrics which can be used to gauge the health of the reef via construction of baseline states and comparison with the extant system. They may be used in conjunction with one another or alone, or with different methods not included here. But how much of a problem is shifting baseline syndrome in coral science?

2.2 Shifting baselines: everywhere and nowhere

2.2.1 SBS in interview data

Throughout coral science, discussion of and appeal to shifting baselines is very frequent. This was true in the interviews I conducted, and also in interviews conducted by others (Braverman, 2020), as well as in the scientific literature itself. What follows are some examples of how this was invoked during interviews, typically in response to being asked about whether the interviewee had seen significant changes to reefs in their careers, or to the question of what a healthy reef looks like:

Quote 7

> ‘oh, a classic example is a group … going out to Egypt … to a place to do what they called a baseline study, right? And now, it was just an algal plane, not a coral lair. But you know, these young guys, they were students, they had gone out, and they were warm, ‘wow’, they could see: 'look there's a fish', now, you can't see that if you're diving in the North Sea - well there are some bits you can - ... And they call theirs a baseline study... no look, chum, it's just… **nothing baseline about it**. It's not a reef anymore even, it really isn't, it shouldn't be called a coral reef. And they just baffled me, **they probably thought I was one of these old people, you know, 'in my day, fish were that big' sort of attitude that you get. And you do get that with people**. But the trouble is, you see we've got the numbers to prove it. You got records of coral cover, you got records of the list of species that are there, corals which is my thing or fish in the case of fishy people.’ 1017

Here, we see not only an appeal to shifting baseline syndrome, in the typical guise of being an age-dependent phenomenon, but also recognition that it is a common trope that old scientists are likely to bring up such problems, so much so that it is named as a stereotypical kind of attitude that older scientists might have (‘in my day… sort of attitude’). The participant implies that sometimes such claims might even be erroneous, but that in some cases they are certainly not, particularly when the correct data is there to back them up.

This quote recapitulates many of the themes found in the original explicit statement of shifting baseline syndrome by Daniel Pauly in 1995. Baselines provide states of comparison for assessing reef health, but unless they are grounded correctly, might well be unduly skewed. Pauly, as a fisheries scientist, leans on slightly different characteristics than some of the ones used in a coral context, but they play the same role: he discussed species composition and stock sizes as representing ecosystem health, in the same way that the participant above focused on the prevalence of algae and coral, on fish size, and (most similarly) on species lists too.

Another participant voiced similar concerns about baselines:

Quote 8

> ‘I started studying biology ‘99. So all the reefs that I've been in the Caribbean, they have been hit already by the bleaching. **And for me, that's the baseline. I don't know them before that**’ 1014

Quote 9

> ‘[on what makes a healthy reef] That's a good question and a hard one. **Because it depends on your baseline in your reference system**. And I guess that those reference systems have changed through time. **So probably a healthy reef for somebody that’s 20 years older than me, will look different to what I will say is a healthy coral reef ecosystem**.’ 1014

Within interviews there was a clear expression of the worries about unreliable observation of the coral reef environment, in terms of judging reef health, due to contingencies in the process of forming a baseline. I explore more of these quotes throughout this chapter. Irus Braverman, in her interviews with coral scientists, similarly noted a widespread worry about shifted baselines. To quote one of her participants: ‘What struck me when I first got to the Caribbean is [that] this is not a coral reef, it’s a weedy forest. But everyone around me spoke about it as if it were a reef. [Because of] the shifting baseline, you forget what is right’ (Braverman, 2020, p.24). This same anxiety has been expressed through other channels too.

2.2.2 SBS in other channels

A review of the literature on SBS suggests that a majority of the work done on it comes from marine scientists, and within this group, those working on fish (Guerrero-Gatica, Aliste and Simonetti, 2019). This is perhaps unsurprising given the marine origins of the concept (via Pauly), and the fact that long term standardised data is less readily available within marine and coral science than terrestrial equivalents. The commonly-articulated concern with non-scientific or non-quantitative historical accounts is that they are generally likely to be more personal, subjective or unstandardised, and so worries about their accuracy add to a feeling that it may not be possible to properly characterise the past states of reefs (Eddy, Cheung and Bruno, 2018). This then leads to the worry that observations and examinations of ecosystems may be inaccurate or systematically skewed to allow for greater degradation to slip under the radar today (Braverman, 2020).

Coral scientists themselves have had various discussions in the literature about the nature of pristine ecosystems, and what exactly an appropriate baseline should be, including calling for more forms of historical and present-day data to be employed to buttress the lack of knowledge about past ecosystems, in order to produce better baselines and counteract shifting baseline syndrome (Jackson, 2001; Knowlton and Jackson, 2008). In a famous paper, veteran coral scientist Jeremy Jackson argued that modern coral scientists are employing impoverished baselines, and that truly pristine ecosystems would have had much greater abundances of various species (Jackson, 2001). Many papers have been written since arguing for different views on what the baselines of specific reef systems should look like (Bruno et al., 2014; Vroom et al., 2006; Vroom, 2011; Greenstein, Pandolfi and Curran, 1998; Sandin et al., 2008).

Concurrently, social scientists have begun to pay attention to the practices involved in baselining nature, looking at the implications for how baselines are constructed. C*onstruction* here implies a degree of contingency (Hacking, 2003), and hence the possibility of shifts or differences between individuals and cases (Campbell et al., 2009; Ureta, Lekan and von Hardenberg, 2020). Note also that criticisms of the very possibility of a *true* or *natural* baseline arise more frequently here, given the problems associated with having a static or atemporal conception of a fluctuating and temporally-extended system (Campbell et al., 2009). (I return to this issue in the next chapter.)

2.2.3 SBS in empirical studies

The widely recognised threat of shifting baselines has driven some researchers to empirically investigate the phenomenon. Of these, most notable is Sarah Papworth, whose dissertation focused on shifting baseline syndrome in ecology generally (Papworth, 2007). Papworth et al. 2008 provide a useful disambiguation between two forms of SBS: generational and personal, both characterised in terms of amnesia. Generational amnesia is where information is lost between people of different ages or experience levels - as has been discussed here so far - resulting in those with longer-lived careers seeing more degradation in modern ecosystems than those who have grown up accustomed to it. Personal amnesia is where the perceptions of an individual shift, such that even those with long-term experience may treat degraded systems as healthy (Papworth, Rist and Coad, 2009, pp.93–94). They also note a range of related phenomena that can also skew perceptions of environmental health, such as false memories of the past, or blindness to change in the environment (Papworth, Rist and Coad, 2009, p.95). Of the three case studies they examine which may potentially demonstrate SBS, they conclude that two do not rule out shifting baselines (but have insufficient data for stronger conclusions), and one provides some indication of shifting baselines – both personal and generational amnesia - although with limitations due to the quality of the data (Papworth, Rist and Coad, 2009, pp.96–98). These studies were all in terrestrial systems and not focused on scientists. Some other studies have found possible evidence for shifting baselines in fishermen (Sáenz-Arroyo et al., 2005) and children (Kahn Jr., 2002), but both are far from definitive due to the high evidential requirements of comparing perceptions of change with actual change in the environment (namely that it requires good long term data about both perceptions and environments) (Papworth, Rist and Coad, 2009, p.94).

Two groups have done studies specifically on SBS in coral scientists. Broadly, both suggest that scientists agree on the values of specific important characteristics representing desirable states for the reefs they study. A study of 50 coral scientists in Florida found broad agreement when asked to characterise the baseline state of their local reefs in terms of optimal percentage coral cover and the most recent year before the present that could be considered healthy: ~33% and 1972 respectively. People of different ages reported very different experiences on reefs. Older people were much more likely to have seen reefs heavily covered in coral species. However, when asked about the optimal baseline for the reef, the answers did not correlate significantly with age (Muldrow, Parsons and Jonas, 2020). Here then, empirical evidence does not suggest that shifting baseline syndrome is an issue for these coral scientists, in terms of the baseline metrics included in the study.

Eddy et al. (2018) found similar results when conducting online surveys with coral scientists about the percentage cover of coral taken to represent a healthy reef, i.e., no correlation with age or time since first experience of a reef. Similarly, they did find correlations between the date of first experiencing a reef, and maximum coral cover experienced: the earlier someone had been on a reef, the more coral-dominated it was likely to be. They also found a correlation between the location of first reef experience and the suggested optimal coral cover for a baseline. Those who first experienced reefs in the pacific, where coral cover is generally higher, estimated a higher percentage coral cover as a baseline, whereas the opposite is true of the Atlantic (Eddy, Cheung and Bruno, 2018). So, whilst older scientists are more likely to have seen reefs with higher coral cover, they do not seem to employ different baselines – in terms of coral cover – than younger ones. However, geographical variation, as with the case of Atlantic and Pacific first-reef-experiences, did seem to drive employment of different baselines, again when looking at a specific set of metrics (coral cover).

Whilst there has not been sufficient research to make strong claims about the presence or absence of shifting baselines, the impacts of SBS are not as obvious as their notoriety might suggest. Herein lies an inconsistency I want to explain. How is it that SBS is so commonly recognised in coral science and yet evidentially absent? There are further interesting questions here too. How do personal memories and observations relate to baselining practices? Why should something labelled as a psychological condition – a *syndrome* - be of concern within contexts where qualitative and personal observations are deprioritised in favour of quantitative and shared ones? I first act out a philosophical stereotype by offering a reframing of the problem, then take a deeper look at baselines and the ways in which they can vary. This suggests a solution to the inconsistency puzzle, some avenues for future research, and points towards a more fundamental problem which will guide the rest of the thesis.

3. Reframing the problem: sources of variation

So what explains this mismatch between awareness of, and evidence for, the existence of SBS? Papworth offers some suggestions: first, that invoking age may be a red herring. Instead of focusing on the age of the observer, the focus should be on the quantity of their experience, particularly the temporal range of their experience (how long ago they first saw a reef) given that these will not always correlate, especially in marine environments (Papworth, Rist and Coad, 2009). Second, Papworth suggests some other psychological processes may be involved, such as personal (rather than generational) amnesia, change blindness, and false memories (Papworth, Rist and Coad, 2009). These are helpful starting points for understanding the paradox here: that it may involve a whole suite of processes linked in different ways to the psychology of the observer, rather than being simply a unitary and personal *syndrome*. It also highlights the complexity of the idea of shifting baselines. In the coral case, the problem is routinely characterised in terms of generations, so understanding it will involve at least explaining why it is perceived as going beyond personal amnesia. Similarly, whilst blindness to ecological change, or the development of false memories, can explain some mismatching between expectations of ecosystems and past or present ecosystems, they do not explain why SBS is hard to detect and yet often invoked[30]. Papworth's first suggestion - the shift to considering quantity of experience, rather than just age - is an important one, and one I want to build on here, because it helps frame the problem more broadly. To build on that further, I start at the nature of coral ecosystems themselves.

Coral reefs are a broad class of ecosystems which can exist in many different forms and vary in many ways. Variation in reef states will either be included or excluded in the baselines, as legitimate variation in a healthy system, or as a movement away from a healthy condition. To give a basic example, specific

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[30] False memories would imply that older scientists were incorrectly assuming ecosystems were changing: this is clearly not the case with coral reefs, which have changed quite drastically in many ways over the last few decades (Anthony et al., 2017). Change blindness would imply scientists not noticing changes had occurred, which again does not seem to be the case with coral science, where awareness of ecosystem change is very high.

baselines are thought to only apply in specific geographical contexts. In interviews geographical variation was permitted as a legitimate reason to employ different baselines:

Quote 10

> '… [talking about cold water reefs in the North Pacific]… The water is much more naturally corrosive, there's more CO_2 … **So a healthy reef there is a very different prospect. So it really depends where in the world you are**, you have to **have that understanding behind you and you interpret what you see**.' 1019

Quote 11

> ' … **coral reefs can look very different in different places** under different conditions, right. For example, I have been working in the eastern tropical Pacific in Costa Rica for my PhD. And along this coast, the reefs are very, very simple. They're usually composed of one or a few coral species. They're quite patchy, and everything, but that still is like a healthy reef for that area. So you always have to find, if you're talking about healthy and pristine, especially, **you have to find the baseline that fits for the area and the place'** 1001

This offers a hint about one of the possible driving factors behind the perception and existence of shifting baselines. In one of the studies I discussed earlier, on SBS within coral science, geography was likely to be a factor in shaping baseline choice, whereas other factors such as age and quantity of experience were not (Eddy, Cheung and Bruno, 2018). So, whilst coral scientists are keenly aware of the risks posed by differing reef health assessments - when driven by inconsistencies in personal experiences over different timescales - they are explicit that a similar process driven by experiences in different geographical areas is not a problem. So, the theories of reef health being employed here are such that geographical variation is to be accommodated by baselines, whereas some temporal variation, at least roughly around the timescale of the lifespan of a few generations of humans, is not to be accommodated. This leads them to conclude that what a healthy reef looks like[31] should not vary (at least in some senses) with time on these scales, but that variation by location is to be expected in some sense.

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[31] Note that I use the locution 'looks like' throughout this thesis, but that I am not thereby privileging the visual, although it is an important part of human-reef relations. In this case, I simply mean what the nature of a reef is supposed to be like, but avoiding visual metaphors is difficult, and is unnecessary as long as they are not taken too seriously.

From here, SBS can be reconceived as a broader phenomenon: variation in understandings of what a healthy or desirable ecosystem looks like. Some variation will be permitted - Atlantic and Pacific reefs should not look the same - but other variation will not - reefs now and reefs 40 years ago should look the same (this is, of course, an oversimplification). This is why age and experience become the focus in discussions of baselining, because (this kind of) temporal variation is a key category to be excluded from baselines[32]. The problem is not a narrow issue of *quantity* of experience biasing standards, but a broader one, including also the q*ualities* of experiences, which are related to a range of different steps in the baselining process. This recasts SBS as a special case of overgeneralisation from one ecosystem state to others, whether that be across geographies, times, or other important categories. This refines and extends the move made by Papworth in her study of SBS. She advocates moving from an age-centred to a quantity-of-experience-centred approach, as old people may not always have more temporally extended experience in marine environments, for example (Papworth, Rist and Coad, 2009, p.94). I advocate here a further move, to include also the impacts of quality of experience, and of the full range of processes involved in baselining.

Indeed, this idea is already implicit in the original formulation of shifting baselines: it is because people’s experiences at different times will have different qualities that they may, as a result, make different judgements based on their experience. The problem is then how they draw inferences across systems which may be very different. Given that this is a problem of understanding variation in the baselining process, it is important now to look at the different ways in which this variation might arise, which will help explain the forms it might take, how it might be best detected, and therefore how serious the SBS problem is.

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[32] Although only certain instances of temporal variation. Others, such as seasonal variation, may be explicitly included, as they are in carbonate budgets, and in variation of bioacoustic patterns (Montgomery and Radford, 2017, p.R506; Lange, Perry and Alvarez-Filip, 2020, p.2).

4. Sources of variation: ecological, methodological, theoretical, affective

So, the problem of shifting baselines is one of understanding *how* variation occurs within a given baselining process, and *when* this variation is considered legitimate. I tackle the how question here, describing it in terms of different levels at which variation can arise in the process of producing and employing a baseline (the levels are of course tightly interconnected, and a useful abstraction for the purposes of this examination). The question of when variation is considered legitimate I examine in the next chapter.

The way the baseline concept was invoked in interviews regularly oscillated between many considerations: the nature of the ecosystem itself, the scientific procedures involved in producing a baseline, and the psychological and affective relations of the scientist to the target ecosystem. These offer a rough outline of the areas where variation may arise in producing baselines. A look at some interview excerpts can help clarify these further. To return to the first quote I discussed:

Quote 12

> ‘oh, a classic example is a group … going out to Egypt … to a place to do what they called a **baseline study**, right? And now, it was **just an algal plane, not a coral lair**. But you know, **these young guys, they were students,** they had gone out, and they **were warm, wow, they could see: 'look there's a fish**', now, you can't see that if you're diving in the North Sea - well there are some bits you can ... And they call theirs **a baseline study**... no look, chum, it's just… **nothing baseline about it. It's not a reef anymore** even, it really isn't, **it shouldn't be called a coral reef.** And they just baffled me, they probably thought I was **one of these old people**, you know, **'in my day, fish were that big'** sort of attitude that you get. And you do get that with people. But the trouble is, you see **we've got the numbers to prove it**. You got **records of coral cover, you got records of the list of species that are there**, corals which is my thing or fish in the case of fishy people.’ [emphasis added] 1017

In this quote there are appeals to several different features of baselines. First, there is appeal to the nature of the ecosystem itself. The interviewee says that the ecosystem had changed into a different type of ecosystem and was no longer a coral reef (“it’s not a reef anymore”, “just an algal plane”). So already there is a sense in which the nature of the ecosystem may be relevant to the baseline employed, and that there may be variation introduced into the process at the ecological level.

Next, there are appeals to the kind of scientific measurement processes often associated with baselines: species lists and records of coral cover, numerically recorded in baseline studies. Having ‘the numbers to prove’ that an ecosystem ought to look like a specific state is one of the key functions of baselines, and so measurement practices are an important feature of the baselining process and offer an avenue for variation to be introduced. The process of doing a baseline study, e.g., of measuring the coral or algal cover on a reef to establish how the healthy system looks, is one which uses *measurements* to produce *data,* and this is in turn taken to be indicative of the health of the reef. Tied to the measurement practices here are the relevant theories associated with reef health which undergird such processes, which again suggests a possible area for variation to emerge between different observers and contexts.

There are also appeals to the ages of the relevant observers (young/old) and to their relevant experience (students/’in my day’). Also mentioned are the experiential qualities of the trip for the young people, as warm and exciting, with fish to see, compared to other environments which might have low visibility, or duller or a less rich range of species. So there is also an affective strand to the baselining process, whereby baselines are also related to how observers feel about the environment they are in, and how this relates to their previous experiences. Again, this offers another possible avenue for there to be variation between individuals and contexts.

This gives four broad areas to consider when looking at how baselines might shift: the ecosystem itself, the scientific understanding of it (broken down into measurement practices, and theoretical background), and the affective relations of the observer to the environment. Participants mentioned such considerations when discussing shifting baselines:

Quote 13

> ‘So we all put on a regulator [diving equipment] **when we're young**. The **first reef you see** - and you'll see - you'll go, wow. But then **someone will say it's not, it's pretty shit, or it didn't used to look like that**. You're just seeing a remnant of what it used to be, what you need to do is go to X, Y, or Z, or stop fishing for 100 years.’ 1008

Quote 14

> ‘… any coral reef ecologist who **started their careers** after about the 1970s would have been diving on reefs where there's a very shifted baseline, **certainly in the Caribbean**, much of the degradation happened prior to the

> 1970s. And the reefs that you see now in the Caribbean are just **completely transformed and will probably never go back to how they looked** in the 1970s' 1012

Again, these interviewees link baselines to specific ecological states. They talk about 'the first reef you see' rather than just the first ecosystem you see. They also raise specific personal circumstances, such as the age of the observer, the date of first experiencing the reef, or time since starting to study reefs. They mention being amazed or disappointed with reef states, and of reefs undergoing long term or irreversible ecological transformations. So whilst baselines are collections of materials and metrics - as emphasised in social studies of baselining (Ureta, Lekan and von Hardenberg, 2020) – they also weave together an ecosystem state, a set of measurements, a background theory for understanding these measurements, and the affective relations the observer has with the target ecosystem. This offers a range of possible ways for there to be variety within baselining processes, which I explore in more detail now.

4.1 The ecosystem level

The first important level of variation to recognise within the baselining process is within the target ecosystem itself. Ecosystems maybe be stable to different degrees, and understanding exactly how and why ecosystems change, on a given timescale, has been a matter of considerable historic debate for as long as the ecosystem concept has existed: for example in debates over the nature or existence of successionary processes (see e.g. Clements (1916); Odum (1965); Chang and Turner (2019)). However, what is increasingly accepted is that ecosystems are places of flux, and that linear changes and predictable stable states do not always hold on broader timescales or as generalisations across different systems (Gillson, Ladle and Ara, 2011; Chang and Turner, 2019).

4.1.1 Geography and phase shifts

Turning to coral reefs particularly, over the last few decades they have gone from being treated as more stable entities which rarely change, to fragile ones in which change is frequent (Sapp, 1999, chap.10; Ankeny and Leonelli, 2019). These changes may operate over different timescales, for different reasons, and in different ways. Many such changes have been driven by the impacts of anthropogenic activity on reef systems, which are increasingly stark. However, it is also recognised that there is significant variability between reef ecosystems even ignoring anthropogenic influences, notably reefs in different places - as mentioned in section 3. As such, comments like the following were common:

Quote 15

> ‘[on what a healthy reef looks like] I think it depends where you are in the world … they all look really different to each other. And I don't necessarily think that's cause they're in different states of health.' 1003

Quote 16

> 'The reef in Utila is kind of a mix where it's … **it's actually pretty decent for Caribbean reef**. But at the same time, you do get spots where there's lots of algae cover. And that's generally a symptom of overfishing of the herbivorous fish.' 1004

Quote 17

> ‘I mean, in Palau, it's a good example, you have these lagoon reefs, which have kind of a lot of freshwater input, it gets very warm, can be slightly acidic, it's a little more murky. And then you have the really clear offshore reefs. **And obviously, so the coral species that live in those two habitats are completely different. But they're both natural habitats, and they're both healthy, but they look entirely different**.’ 1009

Here, it is accepted that geography can drive variation amongst reef ecosystems, and so the same baselines will not be suitable for different systems. But this isn’t the only sort of ecosystem variation which is relevant. One interviewee expanded on this when asked about the future of reefs:

Quote 18

> 'You know, and the reality is, **probably we're going to see some sort of new ecosystem emerging**. And we don't really know what, you know, is that going to be hard coral dominated or soft coral dominated? Is it going to have the same sort of fish assemblages? Or is it gonna have different assemblages? … and so I wish people understood that what we're talking about when we talk about change on reefs is, is change, is not disappearing reefs. **… if reefs change into a new ecosystem there's just as much reason to understand, work with, protect that new ecosystem as there is than it was with the old, perhaps even more so**.' 1003

Here, variation is introduced when a new ecosystem emerges from the old. The interviewee is open to the idea of *re-baselining* this system, arguing that it may be necessary to ‘understand, work with and protect’ it. That is, ecosystems themselves can introduce significant variation into the baselining processes by undergoing transformations into different states. Whilst some of these states may be considered simply degraded versions of pre-established baseline states, others, as in the quote above, may warrant their own new baseline, changing how the ecosystem is assessed. These two outcomes may occur simultaneously, with a system being considered both degraded (when compared to the old baseline state) and healthy (when compared to the new baseline). This kind of nuance can be seen here:

Quote 19

> 'So what you normally get **is even in a degraded reef habitat, you still actually have quite a functioning ecosystem**. **It's a different ecosystem** - scientists say you go through this phase shift so you move from corals to algae or something along those lines. But you still get a functioning ecosystem in my book, different, but functioning, and that will survive for a period of time, but then if you're not getting that aggregation of calcium carbonate from living corals, then the reefs will flatten, and then you'll lose all that rugosity. ' 1015

Quote 20

> '**But what I'm telling you is [about] hard coral reefs**, **because there are also soft coral reefs** … in some sites in the Caribbean the hard coral reefs have been a replaced by soft corals in forming of the structure of the reef. **I have never been in such a reef, so I wouldn't be able to tell you how a healthy reef of that [type] will look**' 1014

In this case, the interviewee argues that a degraded system may also simultaneously be considered functioning, particularly once it has undergone a phase shift and become a different sort of ecosystem. In the second quote, reefs which come to be dominated by other types of coral (soft coral) are treated as amenable to assessment by different criteria, with the speaker explaining how a healthy hard coral reef looks but that this does not necessary apply once this has changed to a soft coral system. In some cases then, ecological variation may warrant the employment of a different baseline to that which was there before – a re-baselining - although when exactly this is appropriate may be unclear and contentious (and is the topic of the next chapter).

This is a problem common to many kinds of modelling and data production processes: systems targeted by scientific processes will change after the data or model has been produced (Dupré and Leonelli, 2022; Leonelli and Tempini, 2020). Sometimes, if the system changes sufficiently, a new model may be required to understand it. The same is true here. If an ecosystem changes sufficiently, it may be useful to employ a new baseline (this comes back to the legitimacy question, covered in the next chapter)[33].

4.1.2 Scales

Considering different spatial and temporal scales also allows for different degrees of ecological variation to be introduced. This was expressed particularly clearly by one participant:

Quote 21

> '… [I] had marked transects and went to the same ones every three months, and what I found there was that the reef was, let's say, off top my head roughly 40% coral cover, 30% bare substrate. Beginning to end, it was still the same percentages. **But it was a different 40% that was coral cover and a different 30% that was bare**. Because that coral would retract, maybe die, maybe grow. … **So there'd be this movement. All in slow motion, which you can't see. The percentage might be 40% coral cover all the time. … But on any one particular point, it might go from being bare to having a coral there to being bare again**, to being covered in algae, having a soft coral on it. ' 1017

Quote 22

> '… And there's variety as well, I think. So if you were to stick your head under water, **in the daytime, you'd hear something completely different to the night time to the evening time**. So yeah, I think that variation, as well as the busyness is a key aspect of a healthy soundscape.' 1003

On a large spatial and temporal scale (e.g. the entire reef, over years) it is recognised that patches of coral will move around. On a smaller scale, a particular baseline might cause an observer to characterise this as a move away from the desirable state: a patch of coral becomes bare, i.e. the organisms there have disappeared, a deviation from the baseline. But zooming out, this this type of change may be expected. The same applies in bioacoustic contexts, where we are told to expect 'completely different' sounds indicative of a healthy reef depending on the time of day. Others discussed possible seasonal variation on reefs (covered in chapter three). So depending on the scales considered, variation in an ecosystem may be more or less

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[33] Note that this problem also flows through many other areas of science impacted by climate change, such as assessment of marine heatwaves, which also require baseline states for comparison which enable heat spikes to be appropriately characterised but which do not classify steadily warming seas as a perpetual heatwave (Amaya et al., 2023). Such questions are related to the socio-ecological dimensions of science and the need to produce scientific idealisation in a way conducive to the right sort of socio-ecological systems as a result. I cover this in the final chapter.

accommodated by a baseline. The problem is compounded by the many possible scales that corals and reefs can be analysed at:

Quote 23

> 'Well it is… you can have an ecosystem within one coral head. But you can also have the whole ocean being the ecosystem and of course the easiest ones to work at are maybe your reef that you're doing research on… your mangrove transect, something like that' 1017

As indicated here, there are pragmatic reasons to pick certain scales, which reduces the problem of scale choice somewhat, but the process of deciding on a temporal and spatial scale offers an opportunity for variation to emerge in baselining processes. The choice of scale will have an impact of the kind of processes included in the baseline, and the kind of changes which are seen as disrupting the ecosystem, rather than simply a part of it. The question of scale also overlaps with methodological and theoretical questions: one of the virtues of the carbonate budget approach to coral health, for example, is that it can more readily give a dynamic picture of reef health, showing how it changes over time and how sustainable the all-important reef structure itself is (Lange, Perry and Alvarez-Filip, 2020). In the case of algal cover, the choice of timescale will directly impact which disturbances to this are factored in and which are not, a process nicely summarised by the authors of one of the studies on baselines in coral science: '…coral cover is reduced by natural disturbances including predators, storms, and diseases. Therefore, the baseline mean of a seascape or region would be substantially lower than the highest observed value, at least when integrated over time' (Eddy, Cheung and Bruno, 2018, p.10). So depending on the timescale, different values of algal or coral cover are to be expected, simply because ecosystems are variable places.

The overall issue of ecological variation was best summed up in the following quote:

Quote 24

> “It's kind of like trying to define a... I don't know, a forest... there's so many different types of forest. And it's really hard to say, what is a pristine forest?” 1009

This makes the issue more explicit: because coral reefs are a broad class of ecosystems, instantiated in many different forms, displaying significant contingencies, and which vary in response to different ecological conditions, and may be measured at many scales, the ecology of the system itself can drive variation in the baselines employed in a given context. So baselines may be influenced at an ecological level, before we even begin to touch explicitly on the psychology of the observer. (This is visible in the confusion over the term ‘shifting baseline’. Sometimes it is used to mean change within the ecosystem itself, other times in perceptions of the ecosystem (Papworth, Rist and Coad, 2009, p.94).) But considering when to re-baseline an ecosystem is deeply connected to some other aspects of the baseline concept: notably the theories, affective states and measurement tools being deployed in concert with the target ecosystem.

4.2 The measurement level

The next two levels at which variation can enter the baselining process are deeply intertwined with one another: methodological and theoretical levels. B*aseline* refers, in part, to a desirable reef state, invoking considerations about the state of the ecosystem itself: what characteristics does it have? But it also commonly refers to a set of measurements reflecting these characteristics, and so associated with the desirable state. These are regularly emphasised in discussions of shifted baselines:

> *Quote 25*
>
> ‘And people have lost the **baseline kind of memory, the folk memory of what it sort of should be like.** There are so many examples of people going out to an area, which has been hammered, has hardly anything there, to do what they call **a baseline survey**. If you know it, **if you have the numbers, there's no such thing**. It's a survey of a heavily damaged area, but they **think it's baseline because no one has told them otherwise, what it ought to be like**.’ 1017
>
> *Quote 26*
>
> ‘Yeah, **so they'll keep coming back, they won't just go to a new reef each time**, they might go back to the same one again, because it's like a baseline and they can keep adding to that dataset, and that'll get larger and larger, because when you go to new one, you're essentially starting again from scratch' 1018
>
> *Quote 27*
>
> 'And **we're trying to establish the baselines for Brazil reefs**. So establishing baselines is such an important thing, and so you're... I'm fully aware that most of the things that I saw in my life and I thought, Oh, this is a pristine reef. That was not a pristine reef at all.' 1025

Here the roles of measurement, memory, and comparison are all made explicit. People may have personal experiences which lead to the formation of different theories of what a healthy reef looks like. They may take for granted the health of the ecosystem, at least to a degree, and may form personal standards which may be different to those of other people with different experiences. Comparison with other states, it is implied, can help remedy this (‘telling them otherwise’), and measurement can in turn aid comparison. So, a dialectic between personal experience, background theories of health, and measurement practices, emerges here. Baselines are built up through repeated and standardised observations or measurements. They are *established* here through specific practices, through *baseline surveys*, which are the employment of specific metrics to capture the important characteristics of the reef associated with reef health. A focus on specific sets of metrics as part of the measurement process came through strongly in answers about recognising reef health:

> *Quote 28*
>
> 'So obviously, there's multiple layers to that sort of question and to a healthy reef. So you would start with good ground cover of coral. **So, you'd want 80 to 100% coral cover in the ideal world and certainly back in the day that that was, that was achievable. Now, a 40% coral cover would be classed as a healthy reef … and that would look quite substantial, quite an amazing sight**. … But what you also want to see is quite a lot of diversity. So there's hundreds and hundreds of species of coral and you want to see a good representation of that. … I want to just put a caveat on the healthy reef, because we were just talking about corals. But obviously, a healthy reef includes all the other diversity associated with that as well. So healthy fish community, healthy invertebrates, so on and so forth. So the coral stuff is the baseline. But without corals, you don't get anything else. But without the other stuff as well, it's very unlikely you'll get a nice, healthy system.' 1015

> *Quote 29*
>
> ‘…that's quite a hard question to answer. But it kind of **depends how you measure health on a reef**. … Usually you're looking at nice high coral cover. Again, **what constitutes high depends on where you are**. Because in the Caribbean, just naturally, diversity and abundance of coral is a lot lower than in the Indo-Pacific. But kind of proportional, high coral cover. And then diversity of fish is clearly important. Because the bigger the diversity of fish, there are a broader array of things that that ecosystem can support. And if you've got apex predators as well, that's usually a really good indicator of a healthy reef.’ 1011

In the first quote, corals are focused on as a key part of the story: without them, ‘you don’t get anything else’ and hence are the target of measurement practices for assessing health (although they are painted as necessary but not sufficient for a healthy reef system here). This is then articulated in terms of coral cover percentage. In the second quote, this intersection of measurement, theory and ecosystem features is made explicit. Reef health depends on ‘how you measure’ it, but this measurement practice takes on different significance depending on the location. In the Caribbean, lower coral cover is expected.

Both of these answers invoke specific measurement practices for understanding reef health. Part of the way the SBS problem is often formulated hinges on the notion of measurement: it is because of an absence of reliable past measurements of ecosystem states that the baseline problem is so acute (Eddy, Cheung and Bruno, 2018; Braverman, 2020). Irus Braverman similarly noted a key role for methodological and theoretical considerations when thinking about baselines, again centring around the absence of historical data and how measurements are interpreted in terms of indicating reef health (Braverman, 2020).

So baselines are, in part, the product of measurement, and are instantiated in data about the reef. Standardisation is employed to try to remove variation from the observation and characterisation process, much in the same way as standardisation processes have operated in other areas of science (Daston and Galison, 1992). In this way, previously complex and somewhat intangible experiences – e.g. observing and characterising the cover of algae and coral on a reef – become more amenable to comparison across people (Tal, 2016). This would seem to make the measurement level a realm of comparative stability. But despite this, there are still ways for measurement processes themselves to introduce variation into baselines.

A nice illustration of the role for measurement in baselining comes through discussion of the problems with historical coral surveying methods, which were less standardised than many modern methods:

> *Quote 30*
>
> ‘[talking about visiting a reef] I remember, years and years ago, going back, and **we tried to re-survey some sites that had been surveyed about 20 or 30 years before by a group of scientists**, but … it wasn't based on sort of quadrats and counting stuff. **It was based on just descriptions of reef sites** … but the scientists who'd originally done it were still alive at the time. And so we wrote to them… and sent them some photographs. And **we said, you**

> **know, “we went to these sites, and they seem completely different to when you surveyed them... and here's some photos”. And we got back, basically a letter saying, “no, no, they look exactly the same as when we saw them”. So the way they'd described them, in their reports, had just been completely different to the way we perceived them and the way we described them.** So yeah, I think perceptions do change over time. And I think sometimes... they saw them as much more spectacular and high diversity than we saw them as. We saw them as pretty run of the mill reefs. You know, they were okay, there was nothing wrong with them. But we didn't see anything special about them. … And so when they'd said, you know, there are wonderful stands of Porites [a type of coral] species or whatever, and we thought, well, where? And then we sent them the photographs, saying you know, there's obviously been a big decline in the Porites populations and they went “no, no, that looks exactly like they did”. “Fantastic aren't they!” [laughs]’ 1010

So the problem here was that despite offering descriptions of the reef, the original study was ambiguous in a way that was difficult to counteract using normal descriptive language: ‘wonderful stands of Porites’ for one group was ‘run of the mill’ reefs for another. Survey methods employed today to judge reef health are specifically designed to address problems such as these. Instead of having to work out what someone else considers a wonderful stand of coral, specific procedures can be enacted in well-established ways that give easily comparable and checkable results. That is, in this case, quantitative measurement procedures provide a more generalised kind of evidential value by trading it off with other considerations such as precision or nuance. Such procedures can reduce the possibility of assessments being incorrect relative to a specific set of agents - here, coral scientists - by calibrating the study methods and results with a set of practices employed routinely by the relevant group of scientists (Tal, 2016, p.5)[34]. The background theory here is such that variation within the ecosystems studied is ignored in favour of collapsing their health down to a set of variables, i.e. reducing more complex concepts down to more easily measurable ones, which inevitably alters their meaning (Bradburn, Cartwright and Fuller, 2016). I return to this theme in the following chapter when examining how reef health is assessed in practice.

The aim of standardised and quantified measurement techniques is to remove variation introduced by the observer and their relationship to the environment, as well as by the use of different techniques (and associated theories) by different observers. In doing so, those developing such techniques face choices

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[34] This calibration process can also include non-human perspectives, which I explore in the chapter on bioacoustics.

about how to trade off generality, precision and realism (Levins, 1966) amongst other choices. Whilst a shift to quantitative methods for assessing reefs removes some sources of variation, it solidifies methodological choices across all contexts where those same methods are employed.

This makes for an interesting relationship between measurement and variation: whilst measurement practices have been developed which reduce the variation across instances of observation within a given context, employment of a specific methodology across different contexts will obscure differences between them. Recall the earlier insight that coral scientists who first experienced reefs in the pacific are likely to see higher coral cover as healthier in general. There may be good biogeographical reasons behind wanting higher coral cover in the pacific, and yet too much standardisation and quantification would make this difficult to recognise. Another participant made a similar point:

> *Quote 31*
>
> "[talking about assessing reef health] I think most prominent in coral reef ecology that's talked about is the fleshy algae dominated state, **the coral dominated state is the healthy and pristine reef and then the fleshy algae dominated state is the degraded state**. **I think this mostly came from the Caribbean where you could see like very fast changes to coral dominated reefs**. Over recent years, there have been alternative stable states characterized, for example, dominated by cyanobacteria or turf algae, which are like very fine algae growing on the reef or also systems dominated by sponges or other invertebrates, which are just not calcifying. So they basically cover the reef but they won't build the reef." 1001

Here again differences between ecosystems are raised in the context of characterising reef health. Ecosystems may shift into alternative stable states, or may vary due to geography, and metrics such as coral/algal cover only tell a part of the picture. The usefulness of these methods for characterising reef health may vary with location or type of ecosystem, and the optimal values of such measurements may also vary (i.e. the underlying theory about reef health may differ).

On top of this, different measurement methods have different virtues. In coral cover observations, naked eye estimates often produce more variable results, whereas computerised or grid-based methods can help reduce this, producing more consistency when performed multiple times or by repeated observers (Jokiel et al., 2015, p.17). In carbonate budget estimates, different methodologies have different virtues and vices too: hydrochemical estimates of reef growth allow for greater understanding of temporal variation, but may not take biological processes into account (Lange, Perry and Alvarez-Filip, 2020, p.2). The use of different (even very similar) practices will also introduce variation into the baselining process then, and to the extent these are made into a standard, will solidify this form of variation across a range of contexts.

Qualitative description of reefs, of the type discussed above, is an extreme form of this: it is a set of measurement practices with high heterogeneity, with few explicit rules constraining individual observers in the same way, and which allows for a great deal of variation across observers. It can however also allow for more nuanced descriptions of reef environments and a richer role for expert judgement (a key part of the baselining process (Ureta, Lekan and von Hardenberg, 2020)), albeit at the expense of communicability and standardisation. Other methods such as coral cover observations or carbonate budget calculations have to contend with similar trade-offs between these considerations, and which methodology works best will depend on a variety of contextual and pragmatic considerations.

To summarise, there are two key ways in which methodological considerations can introduce variation into the baselining process: first, by obscuring some of the nuances of the systems being studied, for example treating geographically different reefs as assessable by the same health standards, and second, through the variation which is introduced by choosing a particular methodology. In each case, a multifaceted phenomenon (reef health) is collapsed down to a simpler one in order to allow for the kind of broad scale comparisons required in large scale studies and comparisons of the kind conducted in coral science. In each case, theories about how to relate measurements to reef health are also employed, some more explicitly and some more tacitly.

4.3 The theoretical level

Note that simply having a set of measurements of a reef does not make a baseline. Data about some characteristic of a reef, on its own, does not provide a measure of reef health. There is another step by which the measurements must be agreed upon to represent a desirable reef state. Without a background theory of reef health, metrics included in baselines are – in the examples used here - simply sets of measurements with no evidential standing beyond a depiction of the current composition, growth rate or acoustic profile of a reef. In philosophical terms, baseline data is *relational*, standing as evidence of reef health only in a certain context, notably once a background theory about reef health has been adopted (Leonelli, 2015; Leonelli and Tempini, 2020). It is in determining this context that personal experience, including affective relations with the relevant ecosystem, plays an important role, providing parts of the background theories required to ‘hook’ data onto an account of what healthy reefs look like.

To return to the example about qualitative assessments of reefs, we see the broader problem of variation, of which SBS is a subset: different observers produce different baselines for the same environment. Why? It seems, in part, because there are so many possible answers to the question ‘how healthy is this reef?’. Whilst informal language (‘spectacular’, ‘run of the mill’, ‘fantastic’) certainly captures aspects of the reef and renders judgements of their health somewhat comparable across cases, it does so in a way which is not always consistent or easily reproduced. More standardised measurement processes can provide more generality and consistency here, but not without trade-offs. By constraining the judgement process, excluding certain variables and focusing on others, they allow for the development of a system by which reef health can be compared across more cases. This produces evidence which is more mobile, enabling more effective communication about a target system (Leonelli, 2015). The trade-off arises because this process allows for variation both within the ecosystem, and the feature being measured (health), to be ignored, shifting the question from a vague one ‘is this reef healthy?’ to a specific one ‘what is the coral cover of this reef?‘, and using a set of theories to reduce the second question to the first one. This requires a background theory about what makes a reef healthy and how that relates to the relevant set of metrics. So the process of employing certain metrics relies on a set of theoretical considerations in order to make them stand as evidence for the state of the reef.

Baseline data, as with other forms of data, can have different evidential value depending on the methods used to produce it and theories used to assess it. Data generally is mobile and yet does not have evidential value on its own (Leonelli and Tempini, 2020). Baseline data, in coming to stand as evidence for the state of an ecosystem, acts more as a lineage than a single entity. It is produced by studies influenced by the ecological state of the system (e.g. how do we characterise the system – as already degraded, or as an exemplar state?), via a range of possible methodological procedures, then interpreted through a range of background theories about reef health (e.g. the algal/coral paradigm – which will also be relevant to how the ecosystem is first characterised).

So, whilst measurement practices can help prevent variation across cases, they do so in a sense by standardising variation across a group of cases (e.g. within a discipline, a geographic area, a laboratory). This is done by relying on background theories of reef health – such as the algae/coral paradigm referred to earlier – which enable certain measurement results to stand as evidence for some state of the reef. Measurement practices shape and constrain expert judgement in a way conducive to agreement, but are also sites where variation may occur. Metrics may not always line up. Employing multiple sets of metrics can help with this, as can testing them with one another, but part of the issue here is that they are made significant by a background theory of health. Such theories may also vary between individuals: there is notable disagreement between how much algae is considered desirable on a reef, for example (Bruno et al., 2014). This will depend heavily too on the ecological context (as discussed above, sometimes an algal reef will warrant its own baseline, and sometimes it will be seen as a deviation from another). Whilst theories may align in specific cases, such as when discussing reefs heavily studied by a particular group, in terms of a well-entrenched metric, such as the Florida Keys for Floridian coral scientists in terms of coral cover, these theories may not align when stretched to applied to other contexts. Floridian reef scientists may disagree on the health status of their own reefs in non-coral-cover terms, or the health of reefs outside of Florida (even in coral cover terms). Such variation in methodology and theory is also connected to affective considerations, i.e. the kind of emotional and subjective responses reef scientists have to their objects of study, which may be strongly linked to their previous experiences, again offering another possible channel for variation to emerge in during the baselining process.

4.4 The Affective level

Coral scientists are often personally very involved with their objects of study, in that they often care deeply for reef ecosystems and organisms (Braverman, 2018). Papworth et al. also note a role for emotion in baseline setting (Papworth, Rist and Coad, 2009, p.93). The nature of reef ecosystems makes them sites of important aesthetic experiences, as well as sites for making connections with the natural world, or of understanding the place of humans within it. Reefs are, for many, a site for significant meaning-making experiences[35]. Personal experience, and affective relations emerging from this, are important in producing an understanding of the natural world broadly, the ecosystem itself more narrowly, as well as the place of humans within these systems. This was spelt out explicitly by one interviewee in the following way:

> *Quote 32*
>
> [on witnessing a bleached reef] 'And all of the intellectual stuff I'd been reading and trying to work out about the biology of these ecosystems came home to roost, in a way, emotionally, that it hadn't before. And actually the idea of globally rising temperatures, causing bleaching events, at a regularity that was enough to transform the ecosystem, irreparably forever, was suddenly tragic, rather than just being a sort of an obvious conclusion based on some thermal data measures in Morne-à-l'Eau. Yeah, so for me, that experience was, if not the first time, certainly the most powerful time where I've been able to make a link between the science that I do, in understanding how the natural world works, with the, poetry, if you like, of understanding its future, and what that means for people worldwide, both in terms of a very practical sense of how people are going to rely on these ecosystems, but also in an emotional sense of who we are, how we interact with the planet we live on, and what that says about us as a global community of people.' 1003

In this case, the participant explains how the experience of swimming through a bleached reef gave them a deeper insight into the nature of the reef system and its connection to humans. Witnessing the reef in this state communicated something about value of the reef system, in terms of what these changes to it *mean* for people worldwide, i.e. the relational value of the system (Chan et al., 2016) for the participant themselves and for those who rely on reefs. The value relations between scientists and reefs play a key role in shaping baselines and reef science itself, something I explore in the subsequent chapters. Suffice to

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[35] Including David Attenborough, who in a difficult-to-source quote is claimed to have said: "I can mention many moments that were unforgettable and revelatory. But the most single revelatory three minutes was the first time I put on scuba gear and dived into a coral reef. It's just the unbelievable fact that you can move in three dimensions". I wrote to him to ask about this and he confirmed that whilst he thought the quote 'sounded too verbose' for him, he agreed with the sentiment (Attenborough, Personal Communication 2023, see appendix).

say here that the affective connections between reefs and scientists offers another avenue for variation in baselining to emerge.

In another interview, recognition of the role for personal experience and affectivity in shaping scientific characterisations was couched in very reflective terms:

Quote 33

> “[talking about another coral scientist] And he was always arguing like, corals are being impacted by farming, by agriculture, and it's like pollution and fishing that's the problem, right? Until he was snorkelling on the Great Barrier Reef in 2017 and saw it bleach and saw the corals die, you know. Then it's like, “Oh, my god, you all are right. It's not just about like fishing and pollution”. **Like even scientists oftentimes have to see things to like, really, internally accept them**… **really to change their minds about their preconceived opinions**. You know, I know you're studying the philosophy of science. And I think the most striking thing about becoming a scientist over the last 10 to 20 years is **how resilient scientists are to data**, you know, especially like all the senior scientists I work with, they all have their ideas about what's going on. And there's no changing their minds. Like there's just absolutely no paper, no data, no evidence, that'll change their mind about the role of nutrients or fishing or whatever … **So people do change their minds, but they have to experience it**, which is crazy, right? That's not... philosophically, in science, that's not what should be changing your mind. Right? Like your personal experience? It should be like, the data, the numbers, but it's amazing how important it is … [to] experience things to really change your perceptions of what's happening.” 1023

This spells out a key way in which affectivity shapes the baselining process. Striking personal experiences can provide insights into, and a deeper understanding of, ecosystem health generally, that is, informing the background theory of ecosystem health that people possess. It is this that makes shifting baseline syndrome so recognisable and widely discussed, because people can think of times where such striking experiences shaped their minds, and so recognise that the unique pattern of personal experiences they’ve had will shape how they see reef ecosystems[36]. It is this impetus which is behind the idea that everyone needs to see a healthy reef in order to really understand what is happening to environments: a kind of ecological pilgrimage to really understand the potential bounty and diversity of nature, and hence the depths to which abundance and variety have fallen in contemporary ecosystem:

Quote 34

> ‘… and many places, you don't really notice it until you find a reef that doesn't suffer, is the removal of all of the big predators. So you know, there are a few

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[36] The importance of striking experiences in the context of scientific experiments is articulated in more detail by Shapin and Schaffer (1985) and Latour (1993)

> places in the world where you still go and swim amongst all the sharks and huge grouper and things, things that you would have once had around reefs. But most of those have been removed in in many parts of the world**. So I guess there … you feel the sense of loss once you see what reefs could look like, with a fully intact fish community**.' 1002

Quote 35

> 'And I kind of got burnt out working on Caribbean reefs, because just, you know, documenting gloom and doom, documenting the changes for 20 years**. It's kind of fun to go work at a place -** well the coral's all gone from the Galapagos - but the fish communities are mostly intact. **You know, there's still like sea lions and orcas and whales**. And like, I mean, there is fishing. So it's not like, perfectly pristine, **but there's just like a lot more of like an intact, natural foodweb so that it's fun to like, yeah, work in that kind of place**. For a change.' 1023

Whilst the measurement-oriented features of baselines make for easier comparison across cases, personal experiences with reefs provide an affective component and a depth of understanding, in a less formal way, that reports on standardised measurement processes may not. Such qualitative understandings are harder to communicate or compare - as with the case of 'wonderful stand of Porites' or 'run of the mill reefs' above - but carry substantial meaning for the individual, and are used to undergird the more standardised routine forms of baseline assessment. Relations between objects of study and the observer studying them can greatly shape models and data produced in this process (Leonelli and Tempini, 2020). As with many other cases, the historic experiences of the observer will have produced certain relations between them and reefs, and this will shape their view of reef health, that is, the background theories they employ to make sense of measurements, as well as the methods they choose to employ to assess the reef. Affective relations with specific ecosystem states also shapes how the ecosystem is initially characterised, and how different states are perceived (linking back to the ecological level of variation, and the question of when to re-baseline):

Quote 36

> "I keep harking back to Singapore … there's a very tiny sort of recreational diving market there for people, because not many people want to go out and dive on really murky, muddy reefs. But I think people are missing out because I think they're just stunning and beautiful. And I've seen everything from sharks, dolphins, sea snakes, turtles, all sorts of really amazing stuff. You know, diving on those kind of murky, turbid, reefs, and you sort of gain a real appreciation for them, because you kind of think, wow, they're surviving in these weird, really adverse conditions. So yeah, I think that maybe that does come out, that the more you learn about reefs, you sort of go away from just the aesthetic beauty

> and appreciate ... all the things that corals do to be able to sort of survive in these weird environments.” 1012

Here, experience with a distinctive reef system, of the type found in Singapore, which is notably murky and muddy compared with others, leads to a greater appreciation for the unique features of such environments, and for care and appreciation for them. The development of affective relations with different ecosystems will undoubtedly shape the way scientists interact with other ecosystems in the future, such as in the assumptions they make about their state of health, whether they treat them as degraded or simply different types of ecosystem, and the kind of measurement procedures used to assess them.

This mixture of standardised quantitative metrics and affective or personal experience is common to many areas of science. It is integral to the process of expert judgement (Daston and Galison, 1992). Similarly to areas such as medicine, environmental health judgements can take the form of simple observations by an expert, who forms an assessment of the state of the system, for example by walking or swimming through an ecosystem, or, in the medical case, discussing and looking at features of a patient’s symptoms (Ureta, Lekan and von Hardenberg, 2020; Jokiel et al., 2015). In reef cases, the background theory of ecosystem health is used to assess the environment through the personal observation by an expert of the relevant ecosystem. This kind of judgement also plays a role in judging data produced through measurement processes, for example, some coral baseline studies may use photographic methods to produce a visual dataset for visual analysis by a coral scientist, but the scope for interpretation is reduced by the imposition of certain standards on the data, in this case, the narrowing down of the observation to the question of coral cover in a specific spatial and temporal range (Jokiel et al., 2015). Affective relations with objects of study will shape the choice and interpretation of measurement systems, and responses to specific ecosystem arrangements, and so offers another possible level at which variation can emerge in the baselining process[37].

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[37] I argue in the final chapter that such relations are an important part of coral science, because they ensure it is oriented towards the reproduction of multispecies niches, associated with kinds of systems we value for a variety of reasons.

5. Implications: where to look for shifting baselines

So, baselines have multiple levels to them: ecosystems themselves may vary in ways which alter how they are baselined, standardised metrics and background theories which permit comparison of reef health may vary across individuals and contexts, whilst affective relations with ecosystems inform perceptions of those systems, and the background theories and measurement practices used to assess them, thereby helping make measurements evidentially significant, but also allowing for variation to arise. Just getting more data is not a solution to the problem of baselining then, because it can support multiple different conclusions depending on the theoretical, affective and ecological context. This view on baselines also helps show why SBS is hard to detect in coral science.

5.1 Shifts and levels

So, SBS can be reconceptualised as a broader problem of how variety emerges within the baselining process. Because some forms of variation are permitted and others are not, personal experiences may have pernicious or beneficial impacts on the baselining processes, which are to either be corrected or welcomed. Personal experiences with different geographies may predict the employment of different baselines, whereas personal experiences with reefs at different times may not, chiefly because the deliberative processes of science, focused on producing and agreeing upon baselines, work, in this example, to eliminate (some of the) temporal but not (some of the) geographical variation. The quantitative edge of a baseline is a tool for generalisation, chiefly because the standardised processes used in baselining reefs enable discussion of complex properties (reef health) more easily, by using background theories to reduce the question down to a simpler and more easily measured one, such as the cover of algae and coral on the reef.

Recall earlier how the problem of shifting baselines was characterised:

Quote 37

> “It's a survey of a heavily damaged area, but they think it's baseline because no one has told them otherwise, what it ought to be like.” 1017

Quote 38

> “But then **someone will say it's not**, it's pretty shit, or it didn't used to look like that.” 1008

Here, and also in the literature on SBS, the problem is characterised as being driven by a lack of comparison, or awareness of alternative possible ecosystem arrangements. Papworth et al. say something similar: ‘Generational amnesia assumes a lack of communication between generations, and lack of other information on past ecosystems, such as photographs and articles’ (Papworth, Rist and Coad, 2009, p.94). And as I have argued above, specific – usually quantitative - baseline methods and metrics are used precisely because they facilitate this kind of generalised comparison. They can do so over long periods of time (beyond individual lifespans) and across different contexts, because they exclude many sources of variation and narrow down a broader more multifaceted question ‘is this reef healthy?’ to a narrower one ‘what values does X metric - coral cover - have here?’.

As a result of the quantitative baselining process, convergence (over judgements of reef health) is more likely to appear in the metrics used in this context, precisely because these tools are designed to facilitate such convergence: they are subject to more comparison and discussion than qualitative descriptions of the reef environment, because they rely on agreed upon techniques and shared background assumptions, excluding others. Using such measurements in baselines allows for metrics to be hooked on to a more general informal idea of reef health, and doing so freezes some aspects of baseline production. Excluding elements of an ecosystem, and broader theoretical considerations about reef health, reduces the amount a given baseline may vary by when being produced, bringing perceptions of health more into line for a specific case. However, this may not alter the broader background theory of health being employed by the individual.

Studies on SBS in coral scientists look at the metrics commonly used to assess reef health: specifically coral/algae cover, and the most recent year before the present that that reef was healthy. These are exactly the areas where SBS is least likely to be found, because they are the areas where communication, deliberation, and convergence of judgements is designed to happen. That studies looking at shifting baselines focus on the primary metrics used in standardised baselines makes intuitive sense, as these features are easier to communicate, and so naturally easier to study. But this also means variation between people and contexts are unlikely to be detected. Studies have found possible shifting baselines in communities with less formalised comparison practices – such as amongst fishermen (Sáenz-Arroyo et al., 2005) – because the metrics employed may not have been subject to the same forces of standardisation that coral health metrics have.

To observe SBS – or, more broadly, variation in the baselining process – studies should also include areas where shared depictions of reef health are harder to construct. Asking scientists to assess the health of reefs they have not deliberated upon extensively as a group may show more variation, by picking contexts where variation in ecosystems, measurements, theories and affective relations are more likely to exist, i.e. those where processes of standardisation and generalisation have not had as much chance to act. Whilst it may seem like individuals are employing the same rules when judging reef health in a certain context, such as when assessing the health of their local reef along the line of well-entrenched scientific metrics, when they assess different reefs, or the same reef in a different way, previously hidden differences may emerge. What looks like a simple rule being followed by all (e.g. more coral cover means healthier) can fall apart when applied to more contexts (e.g. reefs which are in conditions unsuited to high coral cover)[38]. Multiple background theories of reef health can converge on the same characterisation of a specific reef when using specific metrics, and yet still be significantly different in other contexts, especially where measurement practices are less formalised, or personal judgement is emphasised.

As such, studies might be more likely to find SBS by asking for more subjective assessments, such as rankings of the health of a reef after swimming through or observing pictures of it (rather than using metrics like coral cover). In the quote about qualitative description of reefs discussed earlier, variation in ecosystem assessments was immediately obvious. This is because such description brings in a richer understanding of the perspective a given coral scientist has on the nature of the target system, by allowing for more direct inclusion of elements such as their affective relation to the reef, the role of variation within the ecosystem, and their background theories of reef health. This can be capitalised upon by those interested in the ways scientists judge

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[38] This is an instance of Saul Kripke and Ludwig Wittgenstein's 'rule-following paradox' (Kripke, 2007).

ecosystem health, by using a mixture of qualitative and quantitative methods to understand how the ecosystem is being perceived. Using mixed methods to assess how data is produced and interpreted has been successful in other areas of science studies (Leonelli and Tempini, 2020), capitalising on the different affordances of different methodologies.

In the next chapter, I offer a partial qualitative examination of perceptions of reef health. The role of ecological variation is important in the reef case, because it raises the possibility that observers see systems as different types of ecosystem, as well as in different states of health. Some individuals may be more likely to see an algal reef, in itself, as an ecosystem deserving its own baseline, at least in some contexts. Others may be more likely to see it as a degraded form of a coral reef. So as well as looking at how people assess the health of an ecosystem, another avenue for detecting variation would be to look at how people categorise the ecosystem they are looking at, and whether these judgements line up.

Finally, the reason that SBS is so commonly invoked as a worry by coral scientists is explained by looking at the different possible levels of variation. Coral scientists are faced with frequently shifting ecological systems. Once an ecosystem changes in a certain way, some observers may be inclined to re-baseline it, whilst others may not. Coral scientists have famously strong affective ties to their objects of study, and these may develop differently with different personal experiences. To add to this, the different perceptions of scientists on the likely future fates of reefs, for example in terms of the likelihood of preventing serious climate change, will also alter how they characterise and theorise about ecosystems, and therefore introduce variation into the baselining process. Adding to this the emergence of new methodologies for studying reefs, and different theories (such as functional approaches to reef ecology), coral science sits at the confluence of a range of possible sources and types of variation when it comes to assessing reef health. Given the threats faced by reefs, and the rapid changes in coral reefs and in reef science methodologies and theories, and in the interactions scientists have with reefs, it is no surprise they should be aware of the possibility of variation within the baselining process.

6. Conclusion

I have presented here the puzzle of shifting baselines in coral science, namely that it is often invoked as a problem by scientists and yet there is little empirical evidence for its existence. The first step in understanding this problem is to reformulate it as a broader one of how variation enters the baselining process, and when this is considered legitimate. I have dealt with the former question here by looking at the baseline concept, arguing that it has multiple possible levels where variation can emerge: first, that ecosystems themselves are fluctuating systems which may change to such a degree as to warrant a new baseline from some observers. Next, that the measurement practices and background theories associated with judging reef health also introduce (but may stabilise) particular views of ecosystem health, and so may also be a source of variation. Finally, the affective relations that coral scientists have with reefs – how they feel when studying and observing them – will have an impact of baselining through their responses to specific ecosystems (such as decisions about when to re-baseline a system), employment of different background theories, and the characterisation and employment of baseline metrics. There are, then, many areas where variation can emerge in the baselining process.

Many people can think of times where ecological experiences have impacted themselves and others differently (or themselves differently, at different times), and where they assessed the state of an environment in a different way to someone else. This makes shifting baseline syndrome a commonly-recognised threat, but the multifarious nature of the judgement process makes it hard to detect: areas easy to study (e.g. asking scientists about optimal values of coral cover metrics, or years since healthy state) are those where divergence is least likely to occur. Qualitative studies may help unpick some of this variation, by exploring further what environments mean to the relevant observers. This raises a more fundamental question: which forms of variation within a baseline are legitimate? When is it okay to re-baseline a system? When is a system degraded, and when is it simply different (Hobbs, 2016)? How can we draw conclusions about ecosystem health across different systems, and deal with cases where history can't weigh in decisively on the side of a certain ecosystem state? In short, how do coral scientists judge reef health in practice? I provide some answers to these questions in the next chapter.

Chapter 2 - What is a healthy reef? Ecological health as a nested family resemblance

> "Weeds are flowers, too, once you get to know them." (attributed to A.A. Milne)

Abstract

In this chapter I tackle a question posed in the previous one: in coral reefs, when is variation in a baseline legitimate? I propose a solution to this in terms of value, perspective and family resemblance. I first introduce and contextualise the problem. In other words: how can we distinguish health from degradation in reefs? Next I illustrate it with three examples of changes to reefs: algal domination, microbialisation, and tropicalisation. These, I argue, show that ecosystem health is a *family-resemblance concept,* i.e. can be realised in multiple ways, which may not all share all of the same features (Bradburn, Cartwright and Fuller, 2016). Building on work in the previous chapter – specifically that ecosystems are sites of substantial variety – I argue that health is a family resemblance concept because it is fundamentally evaluative and that characterising changes to ecosystems entails prioritising a certain perspective of the system. Given all of this, how do coral scientists actually distinguish positive from negative changes in practice? I put forward a nested family-resemblance scheme for characterising changes to reef ecosystems, which enables for accounts of degradation and health with varying degrees of generality and precision. Finally, I explore how the arguments here connect *values*, as discussed in philosophy of science, with *value*, as covered by various ecological, economic and social frameworks. This points towards a deeper socio-ecological understanding of coral science itself, which I begin to develop in the next chapter, examining the ways in which various forms of value relate, and how they shape the practices of coral science.

1. Introduction

In the previous chapter I showed some sources of variation which can impact the construction of baselines for assessing coral reef health. This raised an important further question which I address here: when is variation in a baseline seen as legitimate, and when is it seen negatively? In other words, when is a coral reef healthy?[39]

The answer to these questions are both tricky and important. One participant described it as a ‘million-dollar question’ (1003). Coral reefs are increasingly threatened ecosystems. Both degradation and attempts at regeneration are pushing them into never-before-seen (novel) ecological configurations (Hughes et al., 2017) (Graham et al., 2014). The status of such configurations may be unclear or disputed (e.g. Tye Pettay et al., 2015; Stat and Gates, 2011). Distinguishing degraded from healthy reefs should be a simple case of looking for restoration or impediment of some feature of the system, such as structure or function (MacCord and Maienschein, 2019; Vásquez-Grandón, Donoso and Gerding, 2018). But in practice, this distinction is not clear-cut, leading to debates over the status of ecosystems or the desirability of interventions to alter them (Hobbs, Higgs and Harris, 2009; Graham et al., 2014; Filbee-Dexter and Smajdor, 2019; Hoegh-Guldberg et al., 2008). Part of the problem is that the baseline employed is hugely consequential: using different baselines will produce different – sometimes incompatible - answers as to whether a reef is healthy or not (Soga and Gaston, 2018; Ureta, Lekan and von Hardenberg, 2020). This is in part due to the different ways in which baselines can vary, as outlined in the previous chapter, which means that there are many possible baselines for a given ecosystem.

In this chapter I outline more specifically what a baseline consists of and show how different baselines will yield different assessments of reef health for a given case. I use three examples: the algal/coral reef paradigm, discussed in the previous chapter, along with the cases of microbialisation and tropicalisation, which offer further complications for understanding reef baselines. In each case, multiple distinct baselines can be employed, which threatens to make assessments of reef health arbitrary. This also crystalizes the problem: what justifies the employment of a specific baseline?

To solve this, I argue that ecosystem health is a family-resemblance concept, that is, a concept which can be instantiated in multiple ways (discussed shortly).

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[39] I asked this question to interviewees, along with related questions about the functioning of coral reefs and what would be lost were they to disappear. I draw on these and other questions throughout this chapter.

Ecosystems are highly variable and shared systems and health itself is a fundamentally evaluative concept, and so reef health assessments must invoke specific perspectives on the nature of the reef and its value. The result of this is that reef health follows a nested family-resemblance structure, which I sketch here[40]. This shows how reefs are judged in practice by coral scientists, limiting the variation they have to grapple with in a given case by building in considerations about the value of the system. This then raises the question of which forms of value, perspectives and entities are to be considered within coral science practices, which I examine in the following chapters, building up to a socio-ecological account of the role of value in coral science.

2. Baselines

Reef health is compared to a healthy reference state, a baseline. Baselines must be indexed to a timescale, as time greatly alters the significance of events within ecosystems. What impedes aspects of a system on one timescale may restore aspects of it on another (and vice versa). A classic example is forest fire, which may kill many organisms on a short timescale, but be a vital part of regenerating habitats on a longer one (Johnstone et al., 2016). Not only this, but baselines must focus on a specific set of entities and characteristics, as ecosystems have many aspects to consider: compositions, functions, and structures among the most commonly mentioned (Hobbs, Higgs and Harris, 2009; Vásquez-Grandón, Donoso and Gerding, 2018)[41]. Not all of these elements can always be included, as there may be some aspects of ecosystems which it is difficult to restore or prioritise simultaneously, such as predator and prey populations, or populations of organisms occupying similar (or radically different) niches. As such there are multiple non-linear paths of degradation and regeneration in reefs (Rinkevich, 2005; Woodhead et al., 2019).

What exactly does a baseline consist of? To recap and formalise discussions from the last chapter, baselines must include: (1) a desirable reef state (or dynamic set of states); (2) a set of measurable reef characteristics (or proxies

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[40] I build on work in related areas of philosophy to do this, particularly work in philosophy of medicine which recognise that context, interests, and values shape the comparison classes we use for defining diseases in organisms (Kingma, 2007, 2014).

[41] Baselines will also be indexed to a spatial scale, although I assume here that specifying entities and characteristics will do this sufficiently.

for these) which are taken to correspond to that state; and (3) a spatiotemporal scale. Characteristics may include things like structure, function and composition of the ecosystem. A healthy reef is one which resembles a given baseline state. Regeneration is the movement of the characteristics of the system towards those depicted in the baseline state, and degradation away from it. Which sorts of characteristics are included will make a big difference to how changes are characterised. Note that baselines, in order to reflect ecosystems, may often need to be dynamic - i.e. allowing for a range of some variables, or a cycle/pathway - rather than 'states' in a strict static sense (Vásquez-Grandón, Donoso and Gerding, 2018; Ureta, Lekan and von Hardenberg, 2020)[42].

Several factors complicate this picture. How can we ensure we have a good baseline? More broadly, how can we decide how a living system, especially an ecosystem, ought to behave? One view is that the true baseline of a system is given by nature: we must look for e.g. the objective proper functions of coral ecosystems, or how they behaved before significant human disturbances[43]. This provides the baseline (Campbell et al., 2009; Jackson, 2001). I call this view 'ecological absolutism'. Problems arise however, in that what gets included in a specific baseline may vary, given the huge range of entities, characteristics and timescales available for the observer to focus on when describing the system, and the different practices and relations involved in producing the description (covered in the last chapter). As such, people may employ different baselines in the same cases[44],[45].

As a result of these problems, it has been argued that baselines are contingent and constructed (Ureta, Lekan and von Hardenberg, 2020). From this a new

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[42] This is to say that returning to a baseline may be a homeorhetic, rather than homeostatic, process. See Fabris (2018) for more on homeorhesis.

[43] The view of nature as undisturbed before the arrival of humans may often have deep theological roots (Robbins and Moore, 2013) (with thanks to an anonymous reviewer for pointing this out). For more on the idea of a singular pre-human-disturbance baseline, which is is necessarily the most desirable or natural state for an ecosystem to exist in, see Cronon (1996).

[44] There is an interesting parallel here with the phenomenon of adaptive preference in economics, whereby people who live in seemingly objectively impoverished conditions give surprisingly positive evaluations of their quality of life (Nussbaum, 2001, p.135).

[45] Often, in the literature, the people mentioned are scientists, although this applies to any kind of observer. I focus here on scientists, but I do not mean to suggest that they necessarily have privilege or authority when it comes to valuing reefs (although as I discuss in the next two chapters, knowing about a system is often important when valuing it). But many other stakeholders are also important to consider.

problem emerges: if radically different baselines can be employed in a given case, the same reef can be equally well thought of as degraded or healthy. As I show later, this is not simply ambiguity about the degree of degradation, because a focus on different timescales and characteristics can produce mutually exclusive descriptions. This makes the distinction between healthy and degraded reefs arbitrary and threatens to make health simply an expression of the whims of the observer (for more on this view see Lackey (2001)). I call the view that there is no principled or non-arbitrary distinction between healthy and degraded ecological states ‘ecological nihilism’. On this view, ecosystems are not really healthy or functioning, but are simply different from each other, and the labels ‘healthy’ or ‘degraded’ are mapped onto them according to mere human preference.

I present a way between these two extremes in this chapter, and build on this throughout the rest of the thesis. To avoid either of these there must be some reason to favour one baseline over another in some non-arbitrary way. I now turn to three different examples of changes which can occur on reefs. In each case I show how baselines are constructed around the value of the system. This paves the way for an account of reef health which is neither fully arbitrary nor overly restrictive.

3. Three cases: algal domination, microbialisation, tropicalisation

Reef systems need not be *coral* reef systems. At its broadest, a reef is an underwater ridge, and need contain no coral or living things at all, being purely geological. Often, however, a variety of organisms produce and sustain reefs, usually in concert with one another, including algae, sponges, corals and, in the case of regeneration strategies, humans (Sheppard et al., 2017). These organisms may be of vastly different types: whilst coral are Cnidarian animals which exist as polyps and colonies (and are cousins with jellyfish, hydra and anemones), algae are a disparate group of acellular, unicellular and multicellular organisms which lack true organs, generally use light energy to create food, and cause headaches for taxonomists (Sheppard et al., 2017; Vroom et al., 2006). Reefs and corals also contain a wide range of microscopic organisms (Rosenberg et al., 2007). When reefs are mentioned, it is typically in the context of coral reefs, i.e. reefs which corals play a significant role in building. A typical coral-dominated reef will contain much algae as well as coral, however, and algae play important symbiotic roles which are essential for reef development, such as acting as a cement holding much of the rock together (Sheppard et al., 2017). A subset of coral-dominated reefs are the charismatic colourful tourist attractions that most people usually think of when reefs are mentioned. Algae on these reefs is usually kept in check by the grazing of symbiotic reef organisms like herbivorous fish[46]. The trophic structure of undegraded coral reefs – i.e. the pattern of how energy flows through them – typically has multiple levels, with producers (algae and other photosynthetic organisms), and then various levels of consumers (such as fish and invertebrates), with apex predators such as sharks at the top (Haas et al., 2016; Morillo-Velarde et al., 2018).

3.1 Algal Reefs

Reefs may exist in coral or algae dominated states (or intermediaries of these, or other states characterised by other organisms). Under some circumstances, the balance of coral and algae on the reef can be disrupted, shifting the configuration of the ecosystem. One possible set of outcomes is ecosystems dominated by algae. This process can also occur in either direction, with coral takeovers of algal-dominated reefs also possible, although less common (Graham et al., 2013). Algal-dominated reefs (algal reefs) are often a murky green, and support different combinations of organisms, having different ecosystem dynamics to coral-dominated ones (Vroom et al., 2006). It is worth noting here that the ecosystem dynamics of algal and coral reefs vary widely within these categories as well as between them (Fulton et al., 2019; Graham et al., 2014). The circumstances which cause algal takeovers of reefs vary. They can, for example, occur after coral bleaching, or after exposure to high levels of nutrients. Evidence suggests that in many places where anthropogenic stressors are higher, coral systems are more likely to become dominated by algae (Graham et al., 2013). Importantly however, algal reefs also occur independently of human influence, and represent one set of the many stable

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[46] It is worth noting that the term *coral-dominated* is not well defined, and subject to debate. Algae often play a larger role in coral reef building than is commonly realised, and the distinction between coral and algal reefs is not a neat one, with many mixed states existing. I return to these points later. I use the term coral-dominated here to refer to reefs in which coral play a larger role in reef-building than in algal reefs. Some authors have suggested referring to any coral reef as a *coralgal reef,* although this has not caught on (Vroom, 2011).

configurations reef systems can exist in (Vroom et al., 2006; Graham et al., 2013).

As introduced in the previous chapter, algal reefs are typically seen as degraded, and measurement of algae and coral prevalence is a key tool used by coral scientists to assess their health status. This view was summarised in the last chapter by an interview participant:

Quote 39

> '[discussing alternative stable reef states] I think most prominent in coral reef ecology that's talked about is a fleshy algae dominated state, **the coral dominated state is the healthy and pristine reef and then the fleshy algae dominated state is the degraded state**. I think this mostly came from the Caribbean where you could see like very fast changes to coral dominated reefs. Like over recent years, there have been alternative stable states characterized for example, dominated by cyanobacteria or turf algae, which are like very fine algae growing on the reef or also like systems dominated by sponges or other invertebrates, which are just not calcifying. So they basically cover the reef but they won't build the reef.' 1001

Another interviewee expressed it in similar terms:

Quote 40

> "But at the same time, you do get spots where there's lots of algae cover. And that's **generally a symptom of overfishing of the herbivorous fish**, and loss of also important herbivores like sea urchins there. **So you've got a place that would have been pretty healthy, but it's undergone this phase shift where it's been covered more in algae**, and with all the degradation and then the phase shift, there's obviously less fish in in those areas than there would be." 1004

Here, the coverage of a reef by algae or coral correlates with how healthy the reef is. More algae is typically more degraded, and more coral is healthier[47]. This provides a convenient visual metric which may often correlate with degree of anthropogenic influence because many of the anthropogenic disturbances

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[47] Another example of this from the literature: 'We compared the trophic structure and food chain length between two shallow Caribbean coral reefs similar in size and close to each other: one dominated by live coral and the other by macroalgae (i.e., degraded)' (Morillo-Velarde et al., 2018, p.1).

reefs are subjected to will lead to formation of algal-dominated states. This has been represented pictorially in coral science papers too:

This image has been removed by the author of this thesis for copyright reasons

Figure 1 – Diagram showing alternative states of coral reefs, with macroalgal state explicitly shown as degraded, and coral-dominated state as healthy. From Bellwood et al. (2004, p.828).

Here, the movement of the ball down the slope in section B is explicitly labelled a movement into less desirable states, which includes movement from a healthy coral dominated state to states dominated by macroalgae or turf states, then sea urchins, slime, and eventually rock. This offers a depiction of a key background theory influencing construction of baselines in many cases.

But this theory of reef health comes with caveats: not all algal states are necessarily seen as degraded. Participants did recognise during interviews that such ecosystems could be considered healthy or functioning in their own right. To return to two other quotes from the previous chapter:

Quote 41

> '**So what you normally get is even in a degraded reef habitat, you still actually have quite a functioning ecosystem**. It's a different ecosystem - scientists say you go through this phase shift so you move from corals to algae or something along those lines. **But you still get a functioning ecosystem in my book, different, but functioning, and that will survive for a period of time,** but then if you're not getting that aggregation of calcium carbonate from

> living corals, then the reefs will flatten, and then you'll lose all that rugosity.' 1015

Quote 42

> 'You know, and the reality is, probably we're going to see some sort of new ecosystem emerging. And we don't really know what, you know, is that going to be hard coral dominated or soft coral dominated? Is it going to have the same sort of fish assemblages? Or is it gonna have different assemblages? Yeah, you know, and, and so I wish people understood that what we're talking about when we talk about change on reefs is, is change, is not disappearing reefs. … **if reefs change into a new ecosystem there's just as much reason to understand, work with, protect that new ecosystem as there is with the old, perhaps even more so**.' 1003

Here there is a recognition that alternative states which reefs transform in could also be important in their own right 'just as much reason to … protect that new ecosystem', these systems being 'different, but functioning…'. So, depending on the baseline employed, algal reefs, and other alternative reef states, may be seen as degraded or not. Degraded systems can be seen as functioning in a different manner. Newly emerging systems can require protection just as the systems that begat them did. Transitions between coral and algal states may or may not be seen as regenerative or degradative. So why do some systems warrant their own baselines and others not?

Algal reefs are considered degraded because they lack various forms of value compared to coral states. In the quotes above, we are told that algae will 'basically cover the reef but they won't build the reef', that on algal reefs 'you're not getting that aggregation of calcium carbonate from living corals, then the reefs will flatten, and then you'll lose all that rugosity'. So here importance is placed on coral dominated states because they will replenish the reef structure and retain the rugosity of the system – rugosity is the structural complexity which facilitates ecological interactions and ultimately the existence of biodiversity on the reef (Morillo-Velarde et al., 2018, p.8; Knudby and Ledrew, 2007) – whereas algal dominated states will not do this, and eventually the reef will flatten and cease to provide the value associated with biodiversity and complexity, as well as the services derived from this. So it is not so much the specific history of the reef that matters, nor just the facts about how it operates, but the value the reef provides to various entities, including humans and other species.

A similar role for value in baselining is visible in scientific literature on algal reefs. Defenders of algal reefs argue that algae play an under-appreciated role in many reef systems, and that they should be given more precedence in baselines when assessing changes to reefs (Vroom, 2011; Howe, 1912). There is a claim about value underlying this: the low affective value of algae compared to coral has led to it being unduly ignored in baseline construction. This phenomenon, which has been termed the ‘charisma gap’, has been observed in other marine ecosystems too, whereby less charismatic ecosystems or organisms are afforded less resources for research and intervention, despite performing equally valuable ecological and economic roles (Unsworth et al., 2019; Duarte et al., 2008). They also stress the vital roles played by both algal and coral reefs in ecological and economic systems, for example arguing that algal reefs perform many important ecological and economic roles, such as providing habitats for sets of fish and invertebrates, supporting biodiversity and other ecosystems across the seascape, and providing opportunities for tourism and income provision (Fulton et al., 2019). It is sometimes claimed that not all algal reefs are anthropogenic, and that pre-human reefs may have had higher proportions of algae than is allowed for in baselines today. This is chiefly because humans have altered ecosystem dynamics through killing large predators, which has allowed herbivore numbers to increase, and therefore has reduced algal cover (Bruno et al., 2014; Vroom et al., 2006)[48]. The appeal here is to the value of algae as a part of a non-human-disturbed ecosystem. In this case then, the value being appealed to is related to naturalness, wilderness, or independence from human influence.

But these arguments about the value of algal reefs do not apply to all cases. Not all algal-dominated reefs will provide significant ecological, economic or wilderness value. Regardless, however, these claims about the value of algal reefs are used to alter the legitimacy of including more algal elements in

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[48] This suggests that some pre-human-disturbance reefs may have had higher proportions of algae present than some coral-dominated reefs today. This is an interesting case for exploring baselines, given that it has previously been suggested that newer baselines erroneously make greater algal cover seem healthier than older baselines do (Braverman, 2020). The example here suggests that whilst in the short term, coral scientists may have become more accepting of higher algal compositions, in the long term, they may have become less accepting of them. So ‘shifts’ may operate in opposite directions at different timescales. This is an example of why discussing variation in baselining is more helpful than discussing shifts, which unhelpfully imply a singular correct baseline and a consistent direction of change away from it.

baselines, and thereby reappraise the status of reefs with more algae, reducing the extent to which they are seen as degraded (in some cases completely). Arguments for different baselines are accompanied by claims about the value of the things included in them, not just the facts about how reefs were in the past.

3.2 Microbialisation

Another kind of reef transformation raised during interviews is called *microbialisation.* Here, reefs which are normally dominated by macrobes, that is, large multicellular organisms, come to be dominated by single celled microbes (Haas et al., 2016). More specifically, the trophic structure of the reef shifts so that more energy is available for microbes, increasing their biomass and energy use relative to multicellular organisms such as fish and coral (Haas et al., 2016). This has been discussed as ‘the rise of slime’ associated with the loss of structure in heavily human impacted environments, and connected to the destruction of food webs, the loss of large vertebrates and the disappearance of key structure providing organisms (ecosystem engineers) (Helmreich, 2009, p.13; Jackson, 2001, pp.5414–5415). This process may also benefit macroalgae, producing states such as those described in the previous section on algal domination (Haas et al., 2016). The process was described in the following interview discussion:

Quote 43

> “EJ: And so … microbialisation is like a shift from having all these kind of big and medium sized organisms … which, are, I guess, more complex, to having these, this kind of microbial soup?
>
> 1022: Yeah
>
> EJ: This slimy sort of microbial soup that...
>
> 1022: Yeah, that kind of sucks, right? You know, nobody really wants a slimy [laughs]... Like, I mean, in general, everybody kind of has an intuition for it, you know, that you don't really like dirty water, is the way to think about it, and that you basically lose a whole bunch of stuff, you lose colours, and you lose health of macro-organisms and so forth. So people have an intuition for it. But it's literally just that energy balance, like do you put energy into big macro-organisms, or do you put it into small micro-organisms?**” 1022**

So in the process of these transformations you lose macro-organisms and conditions favourable to them, as energy is diverted to microbes. Such microbially dominated reefs, along with other alternate reef states (such as sponge, soft coral and algae dominated forms) have existed for a long time, and shifts to these states may represent reversions to such past reef states (Leinfelder et al., 2012). As such, a return to microbial dominated reef can be seen as a return to a previous ecological state[49]. Indeed, some coral scientists are phrasing the transformations of reefs into such states specifically in terms of atavism – i.e. reversion to an ancestral state[50] – hence there is an explicitly restorative aspect of such changes (Leinfelder et al., 2012). Appealing to history will not help here, then. Ecosystems are too variable, and have histories too long, for facts about the past of an ecosystem to simply define what makes it healthy. In this case, reversion to very ancient arrangements, such as microbially dominated ones, is not seen as reversion to some ancient super pristine state, but as degradation:

Quote 44

> **“**it's actually telling people what will happen in a whole bunch of different ecosystems as we, as we basically, we call it microbialise them. So the more the microbes take over, the worse it is, for the most part, for human things. So that's, I think, probably one of the main things that's come out of this, just from the scientific point of view.” 1022

The implications of these changes are made very explicit. The more the microbes take over, the worse it is for humans. Others in the literature likewise cast these changes in very negative terms (Jackson, 2001, pp.5414–5416). On the other hand, in some contexts, scientists argue that existing and emerging alternative reef states may be worthy of protection and care (Leinfelder et al., 2012; Perry and Larcombe, 2003, p.430). Whilst shifted but low-complexity reefs might not be considered worth protecting, other alternative reef states might still be considered healthy, functioning, or desirable (Leinfelder et al., 2012; Woodhead et al., 2019), as expressed in the quote on alternative reef states earlier ‘there's just as much reason to understand, work with, protect that new ecosystem as there is than it was with the old, perhaps even more so.’

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[49] This might be seen as part of a larger postulated reversion of marine environments to their archaic forms (Helmreich, 2009, pp.64–65). It is also related to the idea, explored later, that labels such as health and regeneration permit varying degrees of abstraction in how they are characterised, i.e. they might require the presence of specific taxa, or have vaguer requirements such as the presence of some living organisms or ecosystem processes. Inkpen and Doolittle discuss the role of abstraction in the context of regeneration in their 2022 book (p.13).

[50] On atavism in biology, see Pence (2022). Leinfelder et al. (2012) suggest an ecological mode of atavism, related to versions of the Gaia hypothesis (or Medea hypothesis), such as the idea of Earth reverting to a pre-great-oxygen-event primordial ecological state (Helmreich, 2009, pp.64–65). With thanks to Nigel Clark for suggesting the Leinfelder paper.

There is once again a key role for value here in shaping baselines. In the exchange on microbialisation, the speaker makes this very clear, invoking what we as humans want and need. We ‘don’t really like dirty water’ and we lose lots of things in the process of microbialisation, including the aesthetic value of the reef (‘colours’) and the health of various macro-organisms. Others have argued that we would lose ecosystem services as well as aesthetic value in such transformations, but not everything of value (Leinfelder et al., 2012). So even though microbialisation can be seen as a reversion to a past reef system, it also involves loss of value for humans, and for other macro-organisms present which we (sometimes) care about.

But this is not to reduce baselines solely to human preferences and whims. A whole range of values inform these situations, including both trivial and more substantial factors. When assessing environments we care about our ability to survive within them, as well as the ability for a range of other organisms to survive too. The conversation continued in this direction:

Quote 45

> “[on the basis of human aesthetic preferences of reefs] And you know, you can get a little handwavish about it, but I think the thing that we're noticing is that we definitely notice clean water, which is essentially associated with the colour blue, which it just turns out people like [laughs], and we probably are noticing big organisms, because if big organisms can survive there, so can we right? In places where big organisms don't survive … it's probably not a good place for us. And then finally, if we see big organisms, there's something for us to eat. Right?” 1022

Whether or not the specifics of this argument hold, it suggests a route beyond ecological nihilism. It is not simply the case that humans arbitrarily often like healthier reefs, or value parts of them, but instead that how we value reefs will depend on our social, physiological and ecological relations with them. There are more trivial considerations (we like the colour blue) which may lead us astray sometimes (healthy reefs do not always look nice), but there are more substantial ones too. The speaker above invokes our own survival and ability to find food as a key part of this. There are many other relations with different organisms and ecosystem components to consider beyond instrumental value (I explore this in the next chapter). Knowing that the environment provides the possibility for organisms we care about to survive and thrive makes us consider that ecosystem healthy. The value relations we have with the environment therefore shape and justify the baselines we employ.

3.3 Tropicalisation

The final example here is called tropicalisation. Here, entire ecosystems begin to move out of their historic ranges[51]. More specifically, coral reefs in warmer climates – closer to the equator – begin to move poleward as temperatures rise and allow (or in some cases, force) them to move (Vergés et al., 2019). Here the process is described by a participant:

Quote 46

> “I mean, **on the upside, on the good news side, the ocean is very, very well connected biogeographically**. So unlike a plant, for example, [which] lives up a mountain, if it gets too warm, that plant really has got nowhere to go, it can't go further up the mountain. **Whereas in the sea, there'll still be places to go, right, because it's all so well connected**. **So with the exception of things that need very, very cold conditions, there should be somewhere for these things to go**. **And that's what we're looking at in Japan, whether the reef systems will simply be able to move northwards**. There's a phenomenon called tropicalisation, have you come across that yet? So, for example, in the Mediterranean Sea, the ecosystems there are being what's called tropicalised, in that, **tropical species are starting to proliferate in what would normally be a more temperate system**. Now, that's partly helped by the fact that the Suez Canal was recently widened and deepened[52], joining the Red Sea with the Med. So that's allowing organisms to come through, like lionfish you might have heard of.” 1016

Quote 47

> “And the kelp forests are dying, but being replaced by table corals. Because they prefer the warm water conditions. And so there is this phenomenon of corals moving northwards in Japan, as the kelp forests retreat due to … heatwaves and just the general warming of the waters. So that's something that's happening. And it was predicted to happen quite a while ago, but the fact that it's happening now rather than in the distant future is very interesting. And it's clearly due to sea surface warming.” 1016

Here, the participant describes the process of kelp forests near Japan – which are accustomed to colder waters – being threatened by sea warming. This causes the kelp forests to die off and the nearby coral reefs – which are

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[51] In parallel with organisms, this might be termed an invasive or non-native *ecosystem*, although note that the meaning of these terms is even sketchier than normal in these contexts: what is the ecosystem invading or non-native to, if the entire ecosystem is moving? It might be termed a novel ecosystem (which usually denotes ecosystems with ahistorical characteristics (Hobbs, Higgs and Harris, 2009) – some partially tropicalised ecosystems will certainly fit this bill), but this case seems different: is an ecosystem novel if it resembles other existing ones but is in a surprising place?

[52] During this interview there was a boat stuck in the Suez Canal for several days blocking it and disrupting global supply chains, so perhaps we can expect more widening and deepening soon.

accustomed to warmer waters – to expand into the space the kelp system was formerly in. Not only might this process help save reef systems, but it may also result in local increases in biodiversity and fish production (Vergés et al., 2019). These changes, which might seem like unambiguous cases of degradation from the perspective of the kelp-associated ecosystems, were seen as at least somewhat positive from the perspective of the participant:

Quote 48

> "Because if you take the big picture of where tropical coral reefs occur, they live up to about temperatures of - I don't know - they can survive down to about 18 degrees or so. And then after that the kelp forests take over. Well how that boundary is gonna shift is very interesting. **It might be that ocean acidification stops coral reefs expanding polewards, which is a big concern because everyone's hoping that okay, the Great Barrier Reef and other reefs will die, but at least those corals can survive in more poleward locations**. But our work in Japan is showing that might not be the case." 1016

The sentiment expressed here might seem somewhat unusual. Normally, an ecosystem shifting into a novel state is seen as degradation (hence worries about invasive and introduced species). But here, the novel state is, at least in some cases, one which might be similar to a healthy ecosystem usually found elsewhere. It is for this reason that the participant mentions the connectedness of the sea as good news. This allows things to move and survive. The only downside discussed is for those things 'at the top of the mountain' that have nowhere else to go. In the case of tropicalisation then, history seems to be on the side of both coral and kelp systems. When an ecosystem moves, do the baselines travel with it? Is a tropical reef in a formerly temperate zone a healthy one? Or is it a degraded kelp forest?

Tropicalisation is seen as a somewhat good thing: 'everyone's hoping that … at least those corals can survive in more poleward locations'. That conditions will become less suited to kelp. Coral 'prefer the warm water conditions', and this is explicitly factored into these assessments of the environment. So rather than warming temperatures being unambiguously degradative of the environment, they are degrading the environment from one perspective (that of kelp) and facilitating the survival of another valued system, the coral ecosystem. This case is a mixed one because there are two valued systems – kelp and coral reefs - which both have important organisms, species, biodiversity, functions and services associated with them, and these are both preserved and lost from the same process (Vergés et al., 2019). Worries about native and invasive species similarly hinge around the value associated with the species in question, and so shape how these labels are applied in different contexts and by different observers (Helmreich, 2009, chap.4). In this case the same logic applies to ecosystems and characterisations of their health status.

Depending on whether we prioritise the web of value associated with the coral reef ecosystem, or prioritise the kelp ecosystem which was previously there - i.e. which organisms’ perspectives and interests we consider - we will employ different baselines. If we value the continued existence of tropical coral ecosystems, the extinction of the existing ecosystems will motivate allowing baselines to move with the ecosystem. So a coral reef out of place is still healthy because the baseline moves with it. Indeed, many people are trying to facilitate exactly this kind of movement through assisted migration of coral species (NASEM, 2019). From the perspective of other organisms however, this coral ecosystem may be unhealthy. In a sense this is no different to the more obviously unhealthy phase shifts – such as microbialisation or algal domination – except the new state is more desirable. A pre-existing kelp ecosystem has shifted into a coral-dominated ecosystem, and so has moved away from its baseline. There are two ways to think about this: one which says that tropical reefs of the right sort are healthy anywhere (the system is re-baselined to suit the tropical ecosystem), and the other saying that the reef is unhealthy because it has supplanted something previously there (according to the kelp baseline). Neither is right in the sense that it is solely supported by facts. But both can be more or less reasonable depending on the context and the value of these systems.

The point here is simply to show there are no strict rules for identifying the correct baselines for a system. Healthy states might have higher or lower biodiversity. Historic states might be less healthy. The value of these states determines which baselines are seen as reasonable, avoiding ecological nihilism (all states are just different, and none better or worse) and absolutism (there is one definite healthy state).

3.4 Value and perspective

In philosophy of medicine and ecology it is often argued that health, illness, wellbeing and other concepts are simultaneously factual and evaluative, that is, they both describe a system and judge it according to some standard (i.e. how the healthy system should operate) (Nelson, 1995; Alexandrova, 2018). Various versions of this claim exist (Conley and Glackin, 2021, p.3; Lackey, 2001; Kingma, 2014). The example cases above all show another instance of this, whereby the value of the various ecological components and arrangements drive their inclusion into baselines. Each of the cases shows how baseline construction involves choices about exactly which timescales, entities and characteristics to include. These are not given by nature but are selected based on their value. Different choices will lead to different baselines and so different characterisations of ecosystems. Algae, kelp, microbes, sponges, sea urchins, and other lifeforms can all take part in different sets of ecological arrangements which will benefit some organisms and not others including arrangements which are mutually exclusive with one another, such as certain macroalgal and microbial formations with coral species, or hard coral and sponges (Bellwood et al., 2004; Leinfelder et al., 2012).

Included characteristics such as functions and structures can be discussed at various degrees of abstraction which will permit various degrees of change to be included within a baseline; for example, specific functions such as providing habitats for a specific endemic reef fish will permit much less change than the function of simply sustaining nearby human life (see Inkpen and Doolittle, (2022); and Maienschein (2012) for similar arguments in microbial and medical contexts). Composition may similarly be detailed at a fine-grained scale, e.g. proportions of different coral species, or a coarser one, e.g. relative proportions of coral (regardless of species) to algae. Even a baseline focused on one kind of characteristic, such as ecosystem function or composition, will therefore involve many choices about what to include in a baseline or not. Focusing on these different entities will change how reef health is assessed. Focusing on some ecosystem functions, e.g. habitat provision for tropical fish, may make the reef seem more degraded than if other species, such as hardier invertebrates (which e.g. survive in both coral and algal systems), are focused on. Likewise, focusing on groups of functionally equivalent species (rather than individual species) will allow for different characterisations, as will different timescales. Which kinds of entities and characteristics are included in baselines and how this is done will depend on how they are valued, something I explore in the next two chapters of this thesis.

In other words, reef states cannot be characterised usefully without taking some perspective on the system in question. To describe changes relevantly and usefully we must weigh in on the side of some sets of interests and not others[53]. This is as true here as in other areas of science. Inflation statistics which do not reflect the interests of the relevant economic groups are not useful (Dupré, 2007). Reef science indifferent to the microbialisation and collapse of complex reef ecosystems is not much use either. Describing reef health is always done from a perspective, and the same cases may look very different from other perspectives (Hobbs, 2016). Just as the baselines used to evaluate a forest will be constructed differently for a lumberjack, bird enthusiast, naturist, or berry forager, so they will also be constructed differently when they are considered with different humans or other organisms in mind. Organisms have different life-worlds, and the same setting will be significant for them in different ways (Uexkull, 2010)[54]. Corals, for example, are both organisms themselves and habitats for many other organisms (Rinkevich, 2005). Baselines may include aspects relevant for some habitats and not others and impact different habitats and organisms in opposing ways. Assessments favouring the algae found in algae dominated reefs will be very different to assessments favouring many other organisms. A healthy system for microbes may involve diverting energy from macrobes. Far from being an example of undue and pernicious direct influence of non-epistemic value on scientific concept formation, as warned against in e.g. Douglas (2016) and Vellend (2019), here value is required to make concepts useful, enhancing rather than undermining their use in scientific descriptions. Baselines, then, operate as claims about the value of certain perspectives. The perceived value of the aspects of the system drives their

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[53] Exactly how the interests of non-humans can be incorporated into scientific processes is something I examine in the bioacoustics chapter. For work on non-human interests, see Goodpaster (1978) and Stone (1972)

[54] With thanks to Sophie Gerber for suggesting the connection with Uexkull and life-worlds

inclusion into or exclusion from the baseline, and the consideration of certain perspectives and not others[55].

Recognising that many different, and some mutually exclusive, baselines may be employed in any case seems to threaten to make health arbitrary, i.e. to suggest a form of ecological nihilism[56]. Suggesting that they are value-laden, and therefore not entirely empirical (in a narrow sense) concepts, seems to further threaten this. But the value-laden aspects of these baselines discussed actually save them from arbitrary application. To argue for the employment of different baselines, the examples I have covered have also included arguments for the value of these baselines. This was not a case of people simply asserting a value preference for a different baseline and ignoring the facts of the case. Instead, baselines act as an area of interesting overlap between value and fact, and between measurement and judgement. As with thick concepts (Putnam, 2002) and mixed claims (Alexandrova, 2018), health, regeneration and degradation claims involve a combination of value and fact, and not in a way that makes them simply undisputable assertions of personal preferences. Here then, the role for value is in gatekeeping what can be reasonably included in a baseline, simultaneously making the baseline relevant to those employing it. Baselines must be justified through arguments about the forms of value they recognise, be that related to affectivity, biodiversity, wilderness, ecosystem functions or economics. These forms of value will relate to social and ecological features of the relevant systems. Both the facts about an ecological process (how do characteristics change) and an understanding of what is valuable about the ecosystem in question (which of these characteristics matter) are required in order to describe something as healthy, regenerated, or degraded. These concepts are thereby only arbitrary if value is excluded from the scientific process, or if value itself is seen as arbitrary.

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[55] A range of other constraints will operate on the construction of baselines too, for example legal or epistemic ones (Hirsch, 2020).

[56] Note that the problem here is not so much that baselines are constructed, given that construction (or social construction) does not necessarily threaten the existential status of something, or prevent it from having significant impact on other aspects of the world (see, for example, Hacking (2003)). The problem here is that many very different baselines can be constructed for a single case. Without recourse to value, there will be no way to adjudicate between them, rendering the descriptions built on top of them entirely contingent upon arbitrarily employed baselines.

The variability in reef health assessments discussed in the previous chapter are therefore in part down to how people value aspects of living systems. This does not mean that such disagreements are intractable. The philosophy of medicine is instructive here: accounts of disease which highlight a role for value are sometimes charged with pernicious relativism (the equivalent of what I am calling ecological nihilism here) about what counts as a disease, i.e. they make the concept of disease arbitrary, or make all applications of it equally legitimate, there being no way to dispute them. Such accounts are only perniciously relativist if a very specific metaphysical position is taken on value: that value judgements cannot be reasonably debated (Glackin, 2019)[57]. In most contexts, such a position on value is not usually taken, so in the same way as we can confidently say slavery is wrong (which plainly involves both value judgements and facts), we can say that anthropogenic murky green reefs with little complexity or diversity are degraded[58].

It is because of value judgements that, generally speaking, algal domination is seen as degradation. In many cases, what people value will line up, and so cases will be described similarly (Hobbs, 2016)[59]. This is obvious if we push the case of algal domination even further: in cases of clearly anthropogenic and very low complexity algal reefs, which usually have very low biodiversity too, even advocates of more algae-sympathetic baselines will employ the language of degradation (Fulton et al., 2019; Vroom et al., 2006). Taking account of the value of the entities being described ensures that characterisations of reefs as healthy or degraded are useful and non-arbitrary. Where there are disagreements over which types of value are legitimate bases for constructing baselines, or which perspectives to include, debate will be more intractable.

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[57] I have argued against this view on value in the introduction to this thesis.

[58] Whilst health claims are relative to value, there are still absolutist and relativist positions on value which could be taken here, both of which will allow for value-laden, non-arbitrary and useful notions of regeneration and degradation. Versions of both may allow for some descriptions to be much more reasonable or legitimate than others. Defenders of relativism would argue that a relativist account only implies there is no neutral perspective from which different baselines can be absolutely ranked (e.g. Kusch, 2020; Veigl, 2020). This still allows for baselines to be more legitimate than one another, to be reasonably debated, and for cases to yield widespread agreement. The key difference is whether statements about degradation/regeneration are true objectively (absolutism) or intersubjectively (relativism) or not at all (nihilism).

[59] Note that even if value judgements do line up, factual disagreements may still operate. There are also other influences on baselines, as is explored in Ureta, Lekan and von Hardenberg (2020).

Because they have to include some sets of interests at the expense of others, and some forms of value over others, health and related terms can always be understood in multiple ways. This means that extra work is involved in identifying healthy reefs. Before concluding this chapter, I offer a brief sketch of how this is done in practice and how it might be further formalised.

4. Identifying healthy reefs

The analysis I have presented so far suggests that reef health is fundamentally a matter of both factual and evaluative judgement, and that reef systems may take many possible arrangements. As such, there are many possible ways to define a healthy reef. Concepts which are based on loose or hard to precisely articulate criteria have been termed *family resemblance concepts* (Bradburn, Cartwright and Fuller, 2016; Cartwright et al., 2022)[60]. For such concepts, there is no singular set of features they all share, but they instead have a broad resemblance to one another. Concepts related to health and wellbeing often have this structure, in part because they have normative components (Bradburn, Cartwright and Fuller, 2016, p.5). Another common aspect of family resemblance concepts is that they are often heavily context or user dependent, that is, which features of a phenomenon are relevant to including it as an instance of a certain concept depends on why the categorisation is being done and under what circumstances (Bradburn, Cartwright and Fuller, 2016, p.6). That something is a family resemblance concept is not simply to say that it represents something unreal, or poorly understood. Concepts which are well or poorly understood, and which represent phenomena independent of or entirely dependent on the human mind, may all be family resemblance concepts, or their opposite, 'pinpoint concepts' (Bradburn, Cartwright and Fuller, 2016). That health is a family resemblance concept was alluded to throughout interviews, including in the comparison to forests from earlier:

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[60] Cartwright et al. prefer the term 'Ballung concepts' which denotes the same phenomenon. Whilst I make use of the conceptual apparatus they employ, I use the term family resemblance because it is already well-recognised and more intuitive than the term 'Ballung'.

Quote 49

> “It's kind of like trying to define a... I don't know, a forest... there's so many different types of forests. And it's really hard to say, what is a pristine forest?" 1009

The forest analogy is particularly instructive. Reefs are a broad range of ecosystems which have different features, just as forests do. In a paper on marginal reefs – i.e. those which live in unusual conditions – the authors take up this parallel and the implications for understanding reef health explicitly:

> ‘As for forests, we consider that it is inappropriate to consider one type of coral reef a poor example of another. Partly because of the obvious practical difficulties in the detailed documentation of coral reef systems, … reef science lags behind some other branches of natural science in documenting and acknowledging the different make-up, dynamics, and driving factors behind the variety of communities we find. Not every coral reef can be or ‘‘should be’’ the reefal equivalent of a pristine rainforest deep in the Amazon Basin, and, in many instances, our understanding of the history and environmental variability of the reef is inadequate. Much of this is apparent to increasing numbers of reef researchers and managers’ (Perry and Larcombe, 2003)

The huge variety of these systems is part of the reason why it’s ‘really hard to say’ what a healthy reef is. Not all reefs will conform to the same standards. So how are they judged in practice? How are health assessments possible at all? The first thing to note is that if the arguments here are correct, there is no possibility of a single list of criteria for identifying every healthy coral reef. Instead, reef health will be identified through a family resemblance scheme. This means that all healthy reefs will have some of the properties on a list of reef health indicators, but not all of them will have all of the properties. They will overlap in terms of many of their features, but not be identical.

Furthermore, exactly which list of features will be relevant will depend on the level of abstraction the ecosystem is characterised at, and the kinds of other systems it is compared to. This has strong parallels with health in medical contexts, which depends on comparing an organism to a specific class of organisms (Kingma, 2015). Ecosystems may be grouped together for different reasons at different levels of abstraction. More situated and concrete characterisations of ecosystems will give more detailed lists of features associated with the health of that system:

Quote 50

> 'Well let's go back to my baseline point. So what we think a healthy reef looks like, the answer **is gonna depend on the type of reef and its situation** Elis.' 1019

Quote 51

> ‘[on what a healthy reef looks like] I think it depends where you are in the world … they [reefs] all look really different to each other. And I don't necessarily think because that's cause they're in different states of health. I'm sure they were, **but I think there's, you know, there's biogeographical differences obviously**.’ 1003

Already here we have a few suggestions for reducing the ambiguity of reef health assessments: identify the type of reef, its situation, and the geography of the reef. To start with, specifying the type of reef will make it clearer which perspectives are to be considered in the baselining process. As I showed earlier, some participants recognised that different reef types – even those associated with degradation, such as algal reefs – can be considered functioning ecosystems or worthy of protection when they are considered not as deviations from another ecosystem state, but as ecosystems in their own right (see chapter 1 section 4.1 The ecosystem level’).

It is exactly this tension noted by Elselijn Kingma in discussion of the health of domesticated organisms: should we evaluate battery farmed chicken health relative to their ancestral cousins and environments, or according to their lives now (Kingma, 2020)? The answer is this depends on how we value these systems, and how specific we want to be. In the case of alternative reef states, the sustainability of the reef is a factor which predominates even when considered as an algal reef. It matters if the reef will cease to exist, and in some states the reef occupiers may not be able to provide sufficient calcium carbonate to the reef to prevent erosion[61]:

Quote 52

> “But it's not an actively growing reef anymore. Basically the reef structure was built by corals, but then all the corals died and now it's just algae or soft corals or whatever growing on it, then it's not growing anymore. It doesn't add anything. So it's just the old structure with the new living carpet on it, basically,

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[61] The same concern was articulated in the earlier quotes about alternative reef states: '…. you still get a functioning ecosystem in my book, different, but functioning, and that will survive for a period of time, but then if you’re not getting that aggregation of calcium carbonate from living corals, then the reefs will flatten, and then you'll lose all that rugosity.’ 1015

> **but it wouldn't be healthy from a carbonate budget perspective because it's not growing**.” 1001

So even non-coral reefs may not be considered healthy if they don’t have the living cover expected for that sort of ecosystem (e.g. algae, sponges, etc.) and if they are unable to sustain the structure of the reef over longer periods of time. This gives some basic features of a healthy reef ecosystem in the abstract: it is covered by various possible kinds of living entities, and able to persist over time (although may still be healthy on a shorter timescale even if it cannot offset erosion).

Once it is specified that the reef is to be treated as a *coral reef*, the presence and proportions of coral species begins to matter, as well as the provision of rugosity (structural complexity) on top of the previous concerns about the sustainability of the structure of the reef. The carbonate budget perspective mentioned is focused explicitly on coral reef systems, and takes net reef growth to be a sign of a healthy reef. In other systems, different kinds of budgets can be calculated to check how sustainable the system is likely to be, and that the various ecological forces at work there are in balance in a way considered healthy (Brandl et al., 2019).

After specifying the type of reef, things can be narrowed down even further. Geography, as we have seen, makes a big difference to how reefs are judged:

Quote 53

> ‘… **coral reefs can look very different in different places under different conditions, right**. For example, I have been working in the eastern tropical Pacific in Costa Rica for my PhD. And along this coast, the reefs are very, very simple. They're usually composed of one or a few coral species. They're quite patchy, and everything, but that still is like a healthy reef for that area. Right**. So you always have to find, if you're talking about healthy and pristine, especially, you have to find the baseline that fits for the area and the place'** 1001

In Costa Rica, along a specific coast, the reefs are composed of few species, but that’s healthy for that area. So specifying the kind of reef (coral) and the location (Costa Rica), allows for some of the ambiguities of reef health assessments to be avoided, and local variation (such as patchiness) to be incorporated into baselines. This can be taken even further, by factoring in local conditions:

Quote 54

> “So it's not just a straightforward ‘the more species of corals there are, the better’. In the same atoll, you can have a sheltered lagoon, with different corals, fewer species there, but you can get 80% coral cover, 100% coral cover. On the seaward side of the same island, which is only 100 yards away, you might have four times the number of species, it's forming 40% coral cover, the rest being filled up by turf algae, calcareous algae, and other things like that. And that's the robust one that faces the ocean waves and keeps the whole thing still there after millennia.” 1017

Quote 55

> “[on reef health] So essentially, we measure it...in the field, we measure it mainly on coral cover, and the population size of corals within the reef system, and obviously that has some flaws to it, **because there are some reefs that are highly dominated by corals, and some that are not**. **And there are others that may be perfectly healthy and are not necessarily coral dominated, so the classic example of that would be algal ridges... so these… particularly in the Pacific, you get these very wave swept reef crests that are basically not coral dominated, because they're just too high energy, corals can't survive in that zon**e. So they're dominated by calcifying algae, which are really robust and sort of have microscopic structure, but robust rock like formations that you get on these things. So there are reefs, and parts of reefs that are not coral dominated naturally.” 1010

Here, specification goes even further as we move down a nested scheme of family resemblances. At a more abstract level, coral reefs (often but not always) have a good cover of coral. But when a location and local conditions are specified, such as being on the seaward side of a reef, expected coral cover drops. In some lagoons expected coral cover might be higher. By specifying more about a reef, and situating it in a given context, more of an indication is given about the expected nature of that reef:

Quote 56

> 'So a highly diverse ecosystem will be, well, in terms of coral reef, we know that highly diverse ecosystems are usually a sign of high health. You could also have ecosystems where you don't have high diversity. But that's because that's the nature of that ecosystem, that in general, the diversity in those ecosystems is not that high…' 1014

Here, diversity sometimes corelates with health, but not always, depending on what is expected from the system. There are other factors beyond geography and local situations which will alter how the ecosystem is categorised and assessed, and the inherent messiness of ecology means that variety can never be completely removed from health assessments. Some ecosystems are just different from others. By narrowing down to coral reefs specifically, i.e.

specifying the type of ecosystem, more factors associated with health can be made explicit:

Quote 57

> 'My definition, it's a very simple one. But I would say that if you have lots of corals, you can, it's not a complete picture, but at least you can say well, you have the houses, you have the structure, you have the workers that are building the houses. So this is a really positive thing. So you must have corals, and then you need to see the biodiversity that is associated because the processes that are threatening or removing some elements of the ecosystems are different. For example, corals are dying because of climate change, because of diseases, because of pollution, but fish are dying because they are fished, they are removed. So you could have a reef that is super nice, 100% coral cover, but still no fish because the fish is being removed by a different process. So the first step is having relatively high coral cover, and then diverse communities, diverse communities with lots of fish, a healthy trophic structure, trophic webs. So you have lots of small fish that mostly will eat the plankton, or eat the weeds or eat from the bottom, but you also have like big predators in the system. And this is my idea of a healthy reef.' 1021

Quote 58

> "That's a good question and a hard one. Because it depends on your baseline in your reference system. … However, I think that there are key attributes that you can see in there, like top predators, sharks, and herbivores, fish and also invertebrates. … Absence of disease in the corals, or at least not huge prevalence of them, because there are many diseases that are recurrent or always present in the reef, but you don't have like, massive outbreaks of them. And then hard corals that are giving a structure to the reef. … And you also have oyster reefs, for instance. I also have never dived in oyster reefs, [so] I wouldn't be able to tell you." 1014

Here we get a list of features of healthy reefs. Good coral cover, presence of fish and invertebrates, moderate levels of disease, and a specific type of trophic structure (with small fish, herbivores and big predators). Whilst not all healthy coral reefs will have these features (for example those in extreme conditions – termed marginal reefs – may have lower diversity or coral cover), most will have some of them. This is the family resemblance structure of reef health. By narrowing down the context of the reef we get more specific sets of family-resemblances. So when we just specify reefs without specifying the dominant organisms, there is less of a clue to the kinds of perspectives and values we are concerned with in that situation, and so more possible options for characterising the reef as healthy. Instead, the focus will be on broader properties such as the sustainability of the reef (can it keep up with sea level changes or survive interactions with waves and storms) or whether it has any living components at all. Once you start to specify which kind of reef (e.g. coral) then more of the values and perspectives to be built in have been narrowed down. Now, we will want at least some coral cover of the reef, associated structural complexity (rugosity), an ability to withstand waves and sea level changes over expected timescales, and the kind of trophic structure associated with reefs often (e.g. presence of sharks, fish, invertebrates, not too much algae). But, as we saw before, in some circumstances this might not be the case. This is only, therefore, a rough guide, and can be improved by specifying further the kind of conditions the reef is in. If the reef is in highly disturbed conditions, for example on the seaward side of a reef, the coral cover might be lower. If it’s in an area with highly turbid water, it might be healthy despite much lower coral cover than those in very clear waters. One participant outlined this in a pragmatic way:

Quote 59

> ‘I think what they have in common is that they are diverse, that life is abundant. And these are all relative compared to other ecosystems. So high abundance, high diversity. And just in a not very scientific way, just a hell of a lot going on in a very small space, you know, a lot of different animals, a lot of different shapes, a lot of different sizes, a lot of different colours, a lot of different behaviours, you know, within like a meter cubed of water, you can see animals using the habitat and the sort of, yeah, the, they're just using lots and lots of different ecological niches in that habitat in lots of very clever and intricate ways. And, yeah, it's an ecosystem where you can just sit and look at a very small area and think, wow, there's a there's a lot going on here’ 1003

These kinds of rough and ready qualitative definitions lend themselves to the kind of tropical reef system being discussed in the quote. The species might not be the same every time, but the richness of the reef environment is expected in most cases. A healthy reef has certain virtues, but will not always have all of the virtues associated with other healthy reefs. These virtues are associated with the various ways reefs are valuable for humans and other organisms[62].

By specifying more about the context of the reef, a nested system of family resemblances can be navigated. At very abstract levels, reefs are stone structures expected to persist for certain periods of time with living organisms regenerating them. At more concrete levels, coral reefs are expected to have a certain degree of complexity and coral cover. At even more specific levels, pacific coral reefs in high wave energy environments might be expected to have higher coral cover than Atlantic reefs, but lower cover than those in calmer

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[62] There is a connection here with the virtues of good coral science, which I explore in the final chapter. To pre-empt it somewhat here, good coral science is that which strives to produce healthy ecosystems, that is, it produces valuable socio-ecological states.

waters. But further specification might change which properties indicate health again too. This is not to say that health is arbitrary in reefs, but that it is highly situated, and that there is a trade-off between generality and precision, as has been noted in other areas of modelling (Levins, 1966). By invoking more specific circumstances, the values and perspectives to be included in the baseline are made clearer, restricting which baselines can be employed in a given case. There is no singular baseline for any given case, but nor is there an unlimited range which can reasonably be employed. Tricky questions will remain, for example about when to treat a newly emerging ecosystem as worthy of re-baselining. But this is just to say that we should study the value of an ecosystem before deciding if changes to it are positive or negative. This raises a question which I explore throughout the rest of the thesis: which forms of value are to be included in coral reef science? And how are such values factored in?

5. Implications

5.1 Pristinity, novel ecosystems and future-oriented baselines

Before moving on to the bigger picture conclusions from these arguments, I first want to briefly explore implications for some other ideas from coral science. The arguments here are that baselines (often tacitly) encode the value judgements underlying descriptions of changes to ecosystems (for a similar approach to biodiversity as encoding values, see Sarkar (2019)). Value drives inclusion of different timescales, entities and characteristics into baselines. A result of this is that even those baselines which favour a pre-human ‘natural’ or ‘pristine’ ecosystem state are still choosing timescales, entities and characteristics – i.e. perspectives - driven by value considerations. This makes sense of the tension between looking for correct baselines, and between recognising that different configurations of coral systems have benefits and costs for different organisms. Often, pristine baselines are presented as not only the correct baseline, but also hugely valuable states. See, for example, Jackson (2001), who talks about how much richer a truly pristine reef would seem to us today (p.5416). On my account, it is because of the value of such ecosystemic arrangements that we often consider them the correct baseline to aim for, rather than these baselines being the correct ones and therefore valuable, or it simply being a coincidence that baselines depict valuable states of affairs.

This understanding of baselines, value and health helps explain the controversy surrounding novel ecosystems and ecosystem services. Debate surrounds the status of novel ecosystems, which differ significantly from past ecosystems yet are not necessarily degraded (Hobbs, Higgs and Harris, 2009). Debate over novel ecosystems may be caused by two issues: First, that compared to a single baseline, some characteristics are restored and others impeded in a given case of ecological change[63]. Second, that there are multiple reasonable evaluative standpoints available to construct baselines from, and so several legitimate baselines for a given case.

The problem of multiple reasonable evaluative standpoints being available is crystalised in controversy over ecosystem services. Often, the ecosystem service framework is charged with instrumentalising living things, treating nature as primarily valuable for its roles in serving human wellbeing (Schröter et al., 2014). A feature of baselines I have presented here is at the root of this: even on the same timescale, they may focus on different kinds of characteristic. Ecosystem services, along with the functional approach to ecology often associated with novel ecosystems (e.g. Bellwood et al., 2004; Hobbs, Higgs and Harris, 2009), allow for a focus on the activities of an ecosystem rather than a concern for specific entities or species compositions. Such activities may, if desired, be characterised in very abstract ways, such as simply supporting a wide range of living things, or specifically supporting human wellbeing. By focusing on such characteristics, radical changes in other variables such as species composition can be described as regenerative. Organisms fulfilling similar roles from an anthropocentric instrumental perspective may be able to replace one another without this being evaluated negatively. Even in less anthropocentric guises, organisms may be grouped by their ecological functions and treated as fungible if they perform the same ones (Bellwood et al., 2004). For those with other perspectives on the value of the living system in question, such as those who consider a species intrinsically valuable, sacrificing some species and allowing them to be replaced by others in the name of regeneration will seem absurd. Intrinsically valuing a species may result in its inclusion in a

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[63] Introduction of new valuable characteristics, without impeding or restoring others, may also complicate this. In the language of medicine, this would be an enhancement rather than a treatment, with the difference between these coming down to how the baseline state is conceived (i.e. whether the improvement is a movement towards the baseline or not). The distinction between these can therefore be contentious (Juengst and Moseley, 2019).

baseline, meaning it is not fungible at all, and cannot be lost without moving away from the baseline (Maguire and Justus, 2008). Likewise, for those that value specific historical configurations (sometimes termed ecological or biological integrity (Callicott, Crowder and Mumford, 1999)), baselines which allow for that to be compromised in the service of other valued aspects, such as ecosystem functioning or biodiversity, will seem unacceptable. I return to the interplay of these forms of value and the activities of coral science throughout the next few chapters.

This also helps make sense of the notion of forward-looking baselines, suggested as a solution to our inability to return to pristine states (Braverman, 2020). How can we regenerate an ecosystem back to something it never was? By relaxing a focus on historical species and their compositions, baselines can include some element of the past (e.g. ecosystem functioning) but also represent radical change from it. Even future-oriented baselines, then, may involve return to a historical state, just in a more abstract way. For many people, in cases where a return to a specific composition is not possible, such forward-looking baselines may seem a feasible or desirable way that regeneration can still be carried out. Conversely, a more concrete focus on historical species composition may explicitly deny a place for humans, and prevent any environment with humans in it from being considered regenerated. Debates over such cases will come down to how observers value human-influenced nature, and in part whether human activity is seen as disturbing that value or compatible with it[64] (Callicott, Crowder and Mumford, 1999). Depending on how nature is valued then, and which kinds of characteristic are included in baselines, it is possible to allow for regeneration to take place even when species or structures irreversibly disappear, or where the end-state includes heavy human influence[65].

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[64] This, may, in part, have theological roots (Robbins and Moore, 2013). These views are reflected in different ecological practices, such as treating humans as disturbing conditions (i.e. excluding them from baselines, or not building them into models) or treating them as normal parts of the ecosystem (Inkpen, 2017)

[65] Note that in the extreme, this account of baselines could accommodate a fully artificial reef, designed and manufactured for e.g. economic benefit and populated with charismatic reef species. Baselines could be constructed for this with purely anthropocentric and economic motives, and so the reef could be legitimately described as regenerating with only these considerations in mind. The point of this example is that baselines need not only be applied to non-manmade systems, and may be useful in more artificial cases (e.g., urban ecology). With thanks to an anonymous reviewer for suggesting this example.

5.2 Values and value

The case I have examined here brings out a role for this sort of value in science. In coral science, the ideas of value-ladenness is not well recognised. Baselines are often presented as simply given by nature. Disputes about baselines seem to revolve around factual questions, such as whether the correct timescale has been picked to represent a ‘pristine’ coral reef, i.e. whether the baselines employed have shifted from the true baseline (Jackson, 2001; Bruno et al., 2014). Even when baselines are the focus of discussion, the contingency of our view of nature recognised, and the value of a specific baseline is emphasised, debate focuses on simply pushing the timescale of the baseline back further to the true ‘pristine’ baseline (Jackson, 2001). But the value of reefs is also high on the agenda: people compare them in value to rainforests, stress the many ways humans and other organisms depend on them, and describe the goal of coral reef management as sustaining coral reef contributions to human wellbeing (rather than simply returning reefs to their baseline states) (Knowlton, 2001; NASEM, 2019, p.1; Bellwood et al., 2004). Coral science is filled with appeals to the many ways coral reefs may be valuable to different actors, including affective (Braverman, 2018), economic (Costanza et al., 2014) and ecological (Knowlton, 2001) forms, to name just a few.

Here, the value attributed to aspects of the object of study itself (the coral reef) shapes concepts and practices in coral science, including shaping how evidence is characterised, and so how things are described and responded to (via baselines and labels like health and degradation). Descriptions of reef health are underdetermined by the facts, so value must be employed to adjudicate between descriptions. In this case, these forms of value are (at least in part) non-epistemic: ecological or economic, affective or aesthetic, for example. They are more often applied to particular entities, as in accounts of the laboratory as a site of value production (Pinel, 2020). They aren’t the typical kinds of non-epistemic value discussed in more traditional philosophy of science contexts, which are often instead spoken of in terms of social, political or personal values (Rooney, 1992; Elliott and McKaughan, 2014). Nor is value here influencing science purely through consideration of downstream risk (as in Douglas (2000)). There is, of course, overlap between *value* in the sense employed here, and *values* as regards discussion of non-epistemic values influencing science, for example in the role of aesthetic values guiding science and the aesthetic value of coral reefs. Equally, this kind of role for non-epistemic values generally has been articulated before (e.g. in connection with the multiple goals of science (Elliott and McKaughan, 2014)). However, here I draw more direct connections between these senses of value: value as studied in areas like ecology, economics, and anthropology, and as attributed to entities in the world; and values as influencing scientific processes.

5.3 Incorporating values into science: a role for social sciences

Finally, there are methodological implications from this understanding of baselines. That value underlies these descriptions (and any attendant interventions) makes it more important that those engaged in reef regeneration take account of the multiple stakeholders present. Where there is contention over the description of changes to an ecosystem, recognising baselines as value-driven can help. Baselines represent an arena where scientific measurement and value judgements interact, as with cases of mixed descriptions (Alexandrova, 2018). Incorporating a wide range of values and perspectives in this context is both important and difficult. It is important because debates over ecosystem health may not be resolvable in arguments which only consider facts. Not only this, but when left unexamined, value-judgements represent a potential source of systematic bias[66]. It is difficult because many different forms and sources of value may operate simultaneously, influencing choices during baseline construction in subtle and complex ways.

By making the context of the reef being assessed explicit – i.e. specifying the location, condition, type of reef and other details - it becomes clearer which kinds of entity, timescale and characteristics are being included. Just as with the algal case, elements of baselines will often come packaged with reasons why we should care about them, i.e. the value judgements supporting them. By doing so, disputes may be mediated more effectively, and the source of disagreement located clearly. In the algal reef case, for example, a lack of

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[66] As in cases such as implicit judgements about the value of non-native species skewing the results of ecological studies in under-appreciated ways (Vellend, 2019). I have argued here that in a sense bias is necessary, but this does not mean it should go unexamined.

clarity about baselines hides several different disagreements. Some arguments are about the potential economic value algal reefs could provide for local populations, such as through providing a farm for biofuels. By making clear that the baseline in evaluating reefs is in this case about functions which perform economic roles, it becomes clearer that for some people, this debate is resolved by answering a purely factual question: can this algal reef support local incomes to the same degree as a coral one? However, for others who prioritise different forms of value, such as the intrinsic ecological value of coral reefs, this debate will be harder to resolve.

Once the epistemological, ontological and value commitments of different stakeholders are made clearer, partial overlaps can be looked for, and even in places where there are no overlaps, different ontologies and value schemes can be combined in ways that produce fruitful outcomes for a range of stakeholders (Ludwig and El-Hani, 2020). Such mediation is particularly important given the increasing calls for active methods to save coral reefs, which feature more direct interventions in coral biology and ecology, and so are likely to introduce more novelty (Anthony et al., 2017).

In human cases this is simpler, but in multispecies cases this means also considering non-human values. The forms of value attributed to reefs are regularly examined in economic, ecological and social sciences, or combinations thereof (see, for example, Moberg and Folke (1999) or Braverman (2018)). By shaping baselines and scientific concept formation, these forms of value become interesting in a new sense for those engaged in describing/inducing changes to ecosystems (coral scientists, ecologists, conservationists) and those interested in understanding these practices (philosophers and social studiers of science). In order to understand coral regeneration and the future of reefs, we need to understand the value attributions different groups bring to the table when evaluating changes to coral reefs. Doing this effectively will require a whole suite of valuographic methods, including qualitative ones (Dussauge, Helgesson and Lee, 2015b). In doing so, the socio-ecology of coral science itself can be considered, and developed in concert with attempts to produce combined socio-ecological models of coral ecosystems (Aswani et al., 2015; Hughes et al., 2017). In the context of coral science, the implication is that understanding the value judgements of coral scientists themselves (as well as other stakeholders) is important, given that they have influence over descriptions of and responses to changes to reefs. The ways scientists value reefs and take account of the values of other organisms is the focus of the next two chapters of this thesis.

6. Conclusion

The purpose of this chapter was to chart a path between two extreme positions on the nature of baselines: first, that there is one true baseline for a given ecosystem, and second, that there are no true baselines for a given ecosystem, but instead only expressions of personal preferences. Using cases where reefs may revert to historic states and yet still be considered degraded, or change to novel states and still be considered healthy, I have argued that reef health cannot be distinguished by a single set of criteria. Instead, it requires a situated understanding of the system in question, which enables more and more precise (but still open-ended) judgements of health as more context is given. This is because ecosystem health is partially evaluative and involves taking a perspective on the system in question, namely, which entities, characteristics and timescales to consider. This makes simultaneously social and ecological study of these systems very important in order to understand the complex webs of value enmeshing the various organisms – human and otherwise – present. Including different forms of value in the baselining process will shape not only coral science but the reefs themselves, so understanding the different value relations present between scientists, reefs and reef organisms is important. The next two chapters focus on this explicitly, first looking at two key value concepts from coral science, before turning to techniques for incorporating non-human value into coral science. This helps understand why baselines in reef science come to look the way they do.

Chapter 3 - Between the intrinsic and the instrumental: ecosystem services, intrinsic value, and value relations in coral science

Abstract

In the previous chapters I have shown that the value of aspects of reef systems plays a key role in the process of constructing ecological baselines from which to characterise the reef. In this chapter I explore in more depth the value relations between coral scientists and their objects of study, focusing on two somewhat controversial and seemingly opposing modes of valuation, ecosystem services and intrinsic value. I argue that coral scientists deploy these in ways which sometimes oppose one another but, on closer inspection, overlap to a surprising degree. I pick out different themes which crosscut these modes of valuation and show how they are not as incompatible as is often supposed. The result is a broad, rich and feature-focused toolkit for describing value in reef systems, which denies a strict dichotomy between intrinsic and instrumental value, recognising that living within and alongside other living systems involves both forms of value simultaneously. Later in the thesis, I show how the value relations articulated through these modes of valuation inform the practices and concepts of coral science.

1. Introduction

> “Whether or no[t] it be for the general good, life is robbery. It is at this point that with life morals become acute. The robber requires justification.” (Whitehead, 1978, p.105)

In the previous chapters I have shown that understanding and assessing reef health requires considering the value of the reef relative to various actors. Given the complexity of considerations involved in valuing reefs, understanding their value from multiple perspectives, and producing baselines based on this, I have argued that qualitative study of the perceptions of reef value by coral scientists is required (alongside existing studies of reef value from other methodological and disciplinary perspectives). To do this, I look at two prominent ways of describing value in coral science: the notions of ecosystem services and intrinsic value. In terms of ecosystem services, coral reefs have been rated as some of the most valuable living systems in existence per square meter (Costanza et al., 2014). In terms more related to intrinsic value, they are often considered subjects of strong ecological, affective, cultural and spiritual significance by scientists and other communities (Braverman, 2018), as well as sites of major biodiversity. But if the critics of both of these ways of valuing are to be believed, neither intrinsic value nor ecosystem services are appropriate for articulating the value of nature on their own, and furthermore they are incompatible with one another. The contentiousness of these terms has resulted in a large literature looking at their meaning and their usefulness for conservation (Batavia and Nelson, 2017; Justus et al., 2009; Schröter et al., 2014). Debates in this literature are fairly removed from coral science itself however, where these ways of describing value are employed regularly.

In her book Coral Whisperers, Irus Braverman shows how coral scientists regularly oscillate between states of hope and despair when considering the fate of coral reefs. Underlying this oscillation between oppositional concepts is a deeper sense of hope which connects the two (Braverman, 2018, 2016). I argue that a similar dialectic process is visible here, driven by the same extreme conditions scientists find themselves in: oscillation between two seemingly opposing value systems, ecosystem services and intrinsic value. Coral scientists, I argue, deploy these in ways which sometimes oppose one another but also overlap to a surprising degree. (Braverman's case and the case I explore here are not merely analogous but related on a deeper level, and I return to this connection in the conclusion.)

I argue here that studying the usage of the concepts of *ecosystem service* and *intrinsic value* within coral science can help move beyond debates around them and their supposed incompatibility. Instead of explaining away one term or the other, I instead highlight their overlaps and contrasts, embracing both the unity and disconnectedness in these forms of value (James, 1912, p.47; Shaviro, 2014). I start by sketching the broad definitions of the terms and an outline the range of support and criticism they have faced. I then move on to presenting some data from interviews with coral scientists in which they are employed. I argue that four key themes cross-cut these two ways of valuing, and that as a result that ecosystem services and intrinsic value are not simply reducible to single concepts (following the pattern of a similar analysis by Douglas (2004) of *objectivity*). Compared to the common oppositional depiction, these value systems are productively destabilised in coral science, allowing significant overlap between the two, and so are not as incompatible, impractical (in the case of intrinsic value) or inflexible (in the case of ecosystem services) as has been suggested. The result is a richer vocabulary for capturing and articulating some of the value of reefs, which focuses on the valuable features of reefs but recognises the multiple ways this can be expressed. This also lays the groundwork for a deeper investigation of non-human values in coral reef systems, something I do in the following chapter.

1.1 Value, modes of valuation, and valuography

As outlined in the methodology chapter, in this thesis I conduct what has been called valuography, that is, an empirical examination of the ways value is enacted in specific activities, here, coral science (Dussauge, Helgesson and Lee, 2015b). I discuss value here in terms of *modes of valuation* because these perspectives treat different forms of value as something which are produced and enacted in a specific context, that is, in a way amenable to sociological and empirical conceptual investigation and to incorporation into rich theoretical frameworks, rather than simply pre-determined concepts which are either employed or not (Dussauge, Helgesson and Lee, 2015b; Lee and Helgesson, 2020; Heuts and Mol, 2013). Note that similar approaches also use the term *registers* or *styles* of valuation (Lee and Helgesson, 2020; Centemeri, 2015). I use the term *modes of valuation* here, but all of these terms have a similar practice-first orientation to value. Such an approach is useful in areas where incommensurability of frameworks has previously been presupposed (Centemeri, 2015), as it has been here, particularly because it allows for different modes or styles of valuation to exist side-by-side in a given context, and draws focus onto how they are intertwined with scientific practices (Lee and Helgesson, 2020).

I therefore start by considering both ecosystem services and intrinsic value each as a set of (internally) related concepts and practices, rather than simply as fixed concepts based on transcendent types of value (Heuts and Mol, 2013, p.127). Whilst many analyses of things like intrinsic value are semantic, here I am also interested in pragmatics, and start by assuming only a rough set of associations for each concept, in order to guide qualitative investigation into how they and related notions are used. Through this, qualitative study becomes a useful tool for understanding the many ways different people engage with and value their environments, and can be used to enrich our concepts and understanding of the value of reef systems (Norton and Sanbeg, 2020, p.8). The aim of this chapter is to see how these different modes of valuation - associated with the concepts of ecosystem services and intrinsic value - are reproduced and employed within coral science. Later in the thesis I then look at how they shape and drive coral science activity.

A further reason for focusing on intrinsic and ecosystem service value is that they are both controversial frameworks in their own right, which makes studying them a useful way to examine how values are enacted within the processes of coral science (Dussauge, Helgesson and Lee, 2015b). Coral science itself can be seen as a ‘value-articulating institution’ (Vatn, 2009), that is, it provides sets of rules for how the significance of reefs to a great many stakeholders and organisms is to be captured and presented. Studying how these modes of valuation operate within this system offers a window into how coral scientists value their objects of study, how this shapes the processes and products of coral science, and how this interacts with the broader socio-ecological context it is embedded in. It also helps with moving beyond the deadlocked debates regarding intrinsic and instrumental valuation (Gilliand, 2021, p.716), offering routes beyond semantic disputes for judging the commensurability and compatibility of these ways of engaging with and valuing nature (Centemeri, 2015).

2. Intrinsic value, instrumental value, and ecosystem services

2.1 Defining intrinsic value

First I look at intrinsic value, which is often contrasted to instrumental value. Instrumental value can be defined fairly simply as the importance some entity has for serving some specific purpose (Baard, 2019), for example, sunlight as providing instrumental value for trees, or outrage as instrumentally valuable for *The Daily Mail*. Intrinsic value, conversely, is a somewhat ambiguous concept, given that many different meanings of the term exist, with these sometimes conflated (Batavia and Nelson, 2017; O’Neill, 1992; Deplazes-Zemp and

Chapman, 2020, p.8). To briefly survey some of the meanings that have been put forward:

1. Value which depends on an entity's internal properties, rather than its relations or benefits to some external entity (O'Neill, 1992).
2. Value which depends primarily on what an entity is, or value an entity has *for or in itself*, or *as an end in itself* (O'Neill, 1992; Batavia and Nelson, 2017).
3. Entities with intrinsic value are entities which things can be good or bad for, i.e. they are entities which have interests and can survive or flourish (O'Neill, 1992).
4. Objective or non-anthropocentric value. So, value which is divorced from an external valuer[67], which is often taken to mean divorced from humans (valuation is often taken to be a necessarily conscious process, and one which is largely the domain of humans) (O'Neill, 1992; Hargrove, 1992; Baard, 2019; Deplazes-Zemp and Chapman, 2020, p.8).
    a. A related formulation is value which is independent of human values (Norton and Sanbeg, 2020, p.2).
    b. Related to this (and sense #3) is 'articulated intrinsic value', i.e. value which is unrelated to a human valuer, for example, the value of a marine environment for the squid or limpets which live there (Connor and Kenter, 2019, pp.1252, 1258)[68].
5. Intrinsic value is often associated with entities which are not easily replaced, or cannot be substituted like-for-like with something else (Himes and Muraca, 2018).
6. It is also invoked in relation to infinite value or priceless value (Maguire and Justus, 2008, p.187; Muraca, 2011, p.389), possession of 'trumping rights' which prevent trading off against other forms of value (Hargrove, 1992, p.197), and with beauty and aesthetics (Rolston, 1994).

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[67] But may still be related to external objects, e.g. value due to rarity might depend on how common something is, which depends on the (non)existence of other objects (Kagan, 1998).

[68] This can be a bit confusing. Here, intrinsic value is either the value possessed by an entity which has a goodness of its own, i.e. an entity which things can be good and bad for (O'Neill, 1992), or the value some X has for some non-human Y (Connor and Kenter, 2019), e.g. sunlight is intrinsically good for coral. Here already the blurriness of the distinction from instrumental value is already visible ('X is good for Y' seems like a pretty standard formulation of an instrumental relation).

For reasons discussed in the introduction to this thesis, I do not treat value as entirely objective or subjective. Things matter, and they matter relative to a great many other (living) things. This relation need not be purely mind-dependent but will still be related to various features of the relevant living systems. Even formulations of objective intrinsic value end up admitting a role for some form of subject-relativity, e.g. that strongly objective of value is indexed to specific forms of life – see Connor and Kenter (2019), or Gilliand on Homes Rolston and J Baird Callicott's views (2021, pp.721–722). Here, instead of discussing objectivity or subjectivity, I look at the way value *is related to* different living entities. This is particularly important as objective intrinsic value is often used to mean value which is independent of humans, but not of other lifeforms (i.e. assuming that humans are the only subjects, and that subjectivity simply means mind-dependence, rather than various forms of lifeform-dependence)[69].

Intrinsic value has been ascribed to many entities, and within environmental ethics the question of which entities bear such value has traditionally received a lot of attention: is it only humans, other sentient beings, or all living things, which have intrinsic value, for example? This has been called the demarcation question (Muraca, 2011). This question is taken to be important because it impacts which entities should be worthy of moral consideration (Muraca, 2011)[70].

As is hopefully visible from the list above, further semantic disambiguation can only help so far with understanding intrinsic value and how it is used in coral reef contexts. Lots of possible meanings exist which interrelate in different ways. Rather than treating this as a single concept then, I treat it as a mode of valuation, that is, a set of ways of articulating the value of nature which are not defined in necessary and sufficient conditions, but which bear a resemblance to one another, and are associated with specific ways of engaging with the environment (Centemeri, 2015; Heuts and Mol, 2013).

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[69] One of the key problems with describing intrinsic value as *objective* is taking the notion of objectivity for granted. Analyses of some of the various ways objectivity has been used can be found in Daston and Galison (1992), Douglas (2004b).

[70] Note that discussions of value in ecology often quite quickly take a solely moral or economic tone, something I aim to avoid here.

2.2 Defining Ecosystem Services

It might seem strange to talk about ecosystems as providing services. Ecosystem services (ES) are typically defined as the ‘ecological characteristics, functions or processes that directly or indirectly contribute to human wellbeing’ (Costanza et al., 2017). Put simply, they are the processes in nature which people derive benefits from, i.e. processes which ‘sustain and fulfil’ human life (Daily, 2003, p.227)[71]. It is also important to note that contributions to wellbeing need not be conscious or recognised, i.e., people need not be aware that they are benefiting from the service for it to be a service (Costanza et al., 2017).

Services have been classified in many ways. Most common are four categories: provisioning, regulating, supporting and cultural services. Provisioning services are those which produce goods such as food, timber, fibre etc. (Costanza et al., 2017). Regulating services are those which help control aspects of the environment, such as water cycles, disease, pollination and storm protection (Costanza et al., 2017). Supporting services are basic processes which underlie ecological and economic activity, and thereby indirectly contribute to wellbeing, such as nutrient cycling, soil production, or habitat provision (Costanza et al., 2017). Finally, there are cultural ecosystem services which are those that produce aesthetic, scientific, or other cultural benefits (Gould, Adams and Vivanco, 2020). Both these and supporting services also tend to include services which do not fit into the other categories, such as existence value, i.e. the benefits derived by people from simply knowing that something exists (Costanza et al., 2017; Davidson, 2013). Ecosystem services thereby try to account for the value provided by coral systems in different ways, such as undergirding the economy (via supporting services), or in actively transforming nature in ways which enhance human life or perpetuate the ecosystem and

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[71] An ambiguity is sometimes present in these definitions, in that ecosystem services are sometimes also said to be ‘the benefits that people derive from functioning ecosystems’ (Costanza et al., 2017). This is further complicated by some claims that the processes underlying these benefits are ecosystem functions, but not services (Costanza et al., 2017). This distinction is not always recognised in the literature. Suffice to say that for our purposes here, ecosystem services are ecological processes which (positively) impact human wellbeing. (For negative impacts, see work on disservices (Saunders and Luck, 2016)).

economy (regulating, provisioning and cultural services) (Stålhammar and Thorén, 2019; Costanza et al., 2014)[72].

Ecosystem services might seem a much more unified set of valuation practices given the consistency of the types I have outlined here when compared to intrinsic value. But there is space for variation here. The things labelled a service can vary widely: the provision of wood, the cycling of nutrients and the beauty or spiritual importance of a forest are quite different types of process invoking different forms of value. ES are also noted to be an area of high interdisciplinary activity, and can be used to move across disciplinary boundaries and between policy and scientific circles (Steger et al., 2018; Brunet, 2022; Brunet, Arpin and Peltola, 2019; Ainscough et al., 2019). So as with intrinsic value, I treat ES here as a mode of valuation, i.e. a set of practices and concepts for evaluating a system which are tied together by common themes – such as denoting ecological processes, or being relevant to wellbeing – but not rigorously defined by them.

ES are invoked extensively in many areas of environmental science, often as tools for swaying decision makers or the public, rather than as internal to scientific or academic discussions (Parks and Gowdy, 2013; Brunet, 2022). They are particularly common in coral science. Coral reefs regularly come out near the top of ecosystem service valuations, that is, they provide a high contribution to human wellbeing per unit of area (Costanza et al., 2014; Moberg and Folke, 1999). Many different services can be discerned, such as protein provision, income through tourism and fisheries, cultural significance, recreational value, protection of coastlines from waves and flooding (Moberg and Folke, 1999). They are found throughout many scientific articles, often in prominent locations within them. This is true of big-picture articles about the future of reefs: “Coral reefs support immense biodiversity and provide important ecosystem services to many millions of people”, is the first line of the abstract of Hughes et al., (2017, p.82); as well as of more specific technical articles, such as this article about the role of nutrient availability in host-symbiont relationships

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[72] The reason that they are called ecosystem services, despite also including goods, is that they are intended to extend economic valuation beyond exchangeable goods and extractive value (Costanza et al., 2017). Referring to services rather than goods helps move past the stock-flow model of nature, whereby it is simply a stock of inert resources which flow into the economy as goods, rather than a dynamic and active set of (re)productive forces.

“Coral reef ecosystems are hotspots of biodiversity and productivity which provide vital and extensive ecosystem services”, in the first line of the introduction of Morris et al. (2019, p.678). References are also sometimes woven throughout publications, for example in Lange, Perry and Alvarez-Filip (2020), where the authors highlight the impact of their work on the ability to predict future ecosystem service states of reefs as a key benefit of the reef assessment methodology they advocate.

There is a feature of coral science which might make this tendency for description of reefs as service providers seem puzzling however: the deep affective, emotional, or even spiritual connections between reef scientists and reefs. Such emotional connections have been well documented, notably by Irus Braverman, including stories of professors and students weeping at the results of a 2016 aerial survey of the Great Barrier Reef following a mass bleaching event (2018, p.87). The term ‘ecological grief’, denoting the emotional response of ecologists at the collapse of their objects of study, has also been associated with coral scientists (Conroy, 2019; Gordon, Radford and Simpson, 2019). For a group of people committed to their objects of study in affective, non-instrumental, and non-economic senses, what explains the prevalence of appeals to the instrumental and economic value of reefs in coral science? These modes of valuation do not always seem to sit well with one another. Based on this, the expectation might be that coral scientists use ecosystem service talk reluctantly, or only when communicating with certain audiences (e.g. policymakers), but that they don’t think they’re a good way to capture the value of reefs. I investigated this in interviews, asking whether participants thought ecosystem services were a good way to think about and articulate the value of reefs. The result was a mixture of qualified support and criticism for ecosystem services which hinted at greater compatibility with intrinsic value than might be supposed.

Throughout interviews there were a range of different views on the ecosystem service concept expressed. To start with a more critical example:

Quote 60

> "Well there's a big problem... I mean, there was a... several years ago, there was a lot of big attempts to try to make economic valuations. So to value services, and value reefs in terms of their... the function and ecosystem services that they're providing, **so that you convert everything into a**

> **monetary value. And that has a real danger**… One is that if you add it all up, what do you do if it doesn't actually, if the balance sheet isn't good enough to... so if somebody wants to build a massive oil refinery and says, well, actually, you're telling me that this reef is worth 600 million a year, but I can make 1200 million a year as an oil refinery, so... so it's a really dangerous route to go down because **it's putting an economic value on something that, a lot of it is just simply not 'valuable'... you can't value it as an economic thing**. **So, for example, biodiversity and the intrinsic value of biodiversity, the intrinsic sort of... what's the word... value to humans, is not economic, it's measured in other things, and you can't put an economic value on it. So I think that can be quite dangerous**. …
>
> And then also just the idea that, **that it is a service to humans**, does have some intrinsic issues with it in that … it becomes … **that's not what they're there for**. You start to see it as a something that's... **that whole issue of being put there to provide resources for humans, is not something that I think is true**. And **it's not something that we should be thinking of that way, because it does devalue the system, and devalue it, I think, quite a lot**. …
>
> And I guess the other danger is with ecosystem services, is once you start to degrade your reefs, by doing bad things to them, they then become less valuable [in ecosystem service terms] …" 1010

The first issue raised here is that ecosystem services allow for reefs to be bought and sold in a sense, in that if someone can demonstrate that an action will produce more economic value than is lost in degrading a reef, they are able to argue it would make sense to take that course of action. So here, ES allows for actions which ignore other forms of value, particularly those which are hard to measure in economic terms. The ES framework can fail to include intrinsic value, and so may result in the reduction of all reef value to a simple monetary figure. This is related then to the idea that reefs are not simply there for human use, but have other purposes beyond this, i.e. they have non-anthropocentric value. Finally, a more pragmatic implication of this, is that if the instrumental value of the reef drops due to e.g. degradation, the value of the reef in ecosystem service terms may also decrease, which then makes it easier to justify damaging it further in economic cost-benefit analysis terms. These objections relate quite closely to criticisms of ecosystem services seen elsewhere, and to the incompatibility of ecosystem services with other modes of valuation, such as intrinsic value (more on this shortly). So to the extent ecosystem services do not allow for these forms of value to be considered, they can be dangerous and inappropriate from the perspective of people who value the reef in many different ways. But there were also more positive views expressed:

Quote 61

> “.. I think it's important that people understand that coral reefs serve the nations that ... they're very important ecosystem services. And I don't think, I think often we get caught up in 'Oh, they're so pretty, and we should save them because they're pretty'. And there is huge, just, you know, intrinsic value to that. **But arguably, what we should be focusing on is the value that they provide to these … 500 million people who rely directly on reefs, and those 500 million people, they want those reefs to do well, they don't want them to disappear. … they need them to be storm barriers, and they need them to be able to harvest their fish and … get protein from**, and so I think... we need to, I hope that we can **think differently about engineering reefs to survive, rather than just keeping these beautiful things**. We **need to appreciate that they ... perform services for human beings that are relying on them**. And there's going to be massive economic destabilization as these nations start to collapse, from reefs collapsing. And so I try to emphasize that, and you know, from Britain or the US, we just, we just... you get that in Florida to some degree, for sure. But otherwise, we just can't understand that.” 1026

Quote 62

> “I'm not wholly familiar with criticisms and things like that. But for me, I think ecosystem services are extremely valuable. And I think they're very, very important to consider. **Because a lot of people do rely on coral reefs for survival**. And so that's obviously an important service that the coral reefs have for people. So yeah, I think there's a lot of value in ecosystem services and kind of the value of the reef to people." 1011

Quote 63

> “EJ: are you aware of any of the criticisms of the notion of ecosystem services? And the people that people that dislike the term? Have you ever heard any of that?
>
> 1001: Dislike the term ecosystem services? Um no, I don't think so. I think in my field, with coral reefs, I **think it's something quite important we talk about. Because reefs and people are very connected in lots of parts of the world**. And it's very important. " 1001

Here, participants argue, each along the same lines, that ecosystem services represent a recognition of the heavy dependence of large numbers of humans on coral ecosystems. There is a difference in how they are presented here from the previous criticisms. ES no longer come to signify exploitation of the environment, or commodification, but dependence on it. ES represent the intertwining of the fates of reefs and humans, particularly humans whose subsistence lifestyles make them more directly dependent on reefs for their survival. Ecosystem services therefore serve to remind those in economic systems more divorced from reefs that for many humans they are life-support systems, rather than just beautiful objects. This is still a very anthropocentric guise, but one which highlights human dependence rather than just human extraction.

Beyond simply communicating with specific audiences, ES are focused on an important feature of reefs in their own right, namely the strong connections between them and people. They highlight the intertwining of coral reef and human fates. This shifting between different senses of ecosystem services enables the concept to be both strongly criticised and widely employed, including alongside supposedly incompatible modes of valuation. This was summed up nicely by a socio-ecologist who worked specifically on coral reef ecosystem services:

Quote 64

> “So I work on ecosystem services but … I only engage … with parts of it... so it was a communication tool originally and then it's become more and more a kind of like scientific sort of approach. … **I think there's a huge side of like commodif... you know putting an economic value on nature. So that's one part of ecosystem services**. That's not the part that I really work with, **I’m more focused on the … kind of like, how these different benefits emerge from, or not even emerge, but are co-produced between people in their environment and how they then connect to wellbeing**. So that's how I sort of engage with ecosystem services … **like the benefits that people derive from the environment**, so it's very focused on **what people see, and what people value, and it's recognizing that there are multiple values there and things rather than just the monetary side**. But obviously that's a big strand of the ecosystem services literature.” 1006

So here we have recognition of the problems of ecosystem services, and the aspects which perhaps raise the most compatibility issues with other modes of valuing (commodification, applying economic values to nature). But then we’re told that ecosystem services have many parts, including those more related to the co-production of wellbeing by humans and their environment. This allows for ‘multiple values’ ‘rather than just the monetary side’, and so for ecosystem services to be more sensitive to other ways of engaging with and valuing the environment (Steger et al., 2018; Ainscough et al., 2019). This offers more room for overlap with the senses of intrinsic value discussed earlier. But first it is worth considering the incompatibility of ecosystem services and intrinsic value.

2.3 Criticism, controversies and compatibility

Just as coral scientists have battered around between waves of hope and despair in the course of considering the fate of their objects of study (Braverman, 2018), so too it would seem they are battered around between the unstoppable force of ecosystem services and the immovable object of intrinsic value. But as with the case of hope and despair in coral scientists, on the ground a more nuanced picture emerges, where contrasts and connections between the two extremes can be better appreciated, and strict dichotomies dissolved (Braverman, 2018).

The core criticisms around intrinsic value revolve around its ambiguity, its uselessness in conservation contexts, and its relationship and compatibility with instrumental value. To summarise these briefly: intrinsic value is poorly defined and used inconsistently with no discernible pattern to its application (Justus et al., 2009), is it is impossible to measure or factor in to conservation decisions, owing to its indefinable or infinite magnitude (Maguire and Justus, 2008); it is unclear what it applies to, and is applied beyond the scope of its supposed targets (Muraca, 2011; Justus et al., 2009); it is simply a ‘trump card’ used to signal that an entity cannot be traded off against another or figured into a cost-benefit analysis (Hargrove, 1992, p.199); it is incommensurable with other forms of value, or even with other instances of intrinsic value (Justus et al., 2009); it is sterile and divorced from our way of life (Chan et al., 2016, p.1463). In short, intrinsic value is often painted by critics as an impractical refuge for the naïve and unrealistic.

Many of the criticisms of ecosystem services (and instrumental valuation more broadly) mirror these criticisms of intrinsic value, with intrinsic and ecosystem service modes of valuation sometimes ‘instantiating each other’s criticism’, as has been catalogued in other cases of overlapping valuation practices (Heuts and Mol, 2013, p.129). Ecosystem services are painted as - rather than naïve – a kind of overly pragmatic take on the value of nature which reduces its diverse and considerable value down to (often) a single number, for example: ‘I suggest that the aggregate value of a chunk of nature — its aesthetic beauty, cultural importance and evolutionary significance — is infinite, and thus defies incorporation into any ecosystem service programme that aims to save nature by approximating its monetary value’ (McCauley, 2006b). Various criticisms follow from this: treating nature as a service provider undermines the other, more important forms of value it possesses, such as intrinsic, spiritual, aesthetic, or life-support roles (Sagoff, 2008; Schröter et al., 2014). Ecosystem services perpetuate attitudes which led to the environmental problems they are designed to solve, i.e. they treat nature as simply a resource to be extracted, allow for its commodification by putting a monetary value on it, and are overly neoliberal (Schröter et al., 2014; Fairhead, Leach and Scoones, 2012, p.244; Chan et al., 2016, p.1463). Ecosystem service value is also typically denominated in terms of utility and prices, which may involve reducing it to a single number (thereby compromising nuance) and giving an exchange value to things which cannot be exchanged (Gómez-Baggethun et al., 2010). By placing a price on nature, they open the possibility that someone might pay it (and thereby be given a licence to destroy nature). They are also heavily anthropocentric, solely valuing nature insofar as it satisfies human preferences[73]. As I began to show in the previous section, these criticisms were raised throughout interviews, but not without qualification.

Ecosystem services are associated with instrumental value, and their incompatibility with intrinsic value is in part rooted in the supposed incompatibility of intrinsic and instrumental value more broadly (Justus et al., 2009; McCauley, 2006b). Intrinsic and instrumental value are considered to oppose one another because intrinsic value is often discussed in terms of *what something is* regardless of how it benefits other entities, and instrumental value is specifically about the benefits accruing to other entities. Various famous quotes attest to this: Immanuel Kant on price and dignity (raised by an interview participant – discussed later)[74] or Oscar Wilde complaining about cynics people who “know the price of everything and the value of nothing.” (Wilde, 1893). Philosopher Mark Sagoff fleshes this incompatibility out a bit more: “By ‘putting a price on it’ we abandon the rhetoric of reverence; we regard nature as a resource to exploit rather than a heritage and an endowment to maintain” (Sagoff, 2008, p.252). So a key part of the clash between ecosystem services and instrumental value is related to the distinction between instrumental and intrinsic value.

It is common to treat intrinsic and instrumental value as incompatible or in competition with one another (Justus et al., 2009; McCauley, 2006; Norton and Sanbeg, 2020). The dichotomy between them may also be seen as a ‘dead end’ or intractable (Gilliand, 2021, p.715). Even less polarised positions on this issue

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[73] Further, this value is marginal, i.e. only attempts to value changes in ecosystem service provision, not the entire ecosystem (Gómez-Baggethun et al., 2010).

[74] ‘Everything has either a price or a dignity. Whatever has a price can be replaced by something else as its equivalent; on the other hand, whatever is above all price, and therefore admits of no equivalent, has a dignity. (Kant, 1997 [1785], p.434-435)

involve introducing new categories such as relational values, or new systems such as the Life Framework of Values (Connor and Kenter, 2019) (Piccolo, 2017; Jax et al., 2013), which often carry over the assumption that intrinsic and instrumental value are discrete categories with little overlap. New frameworks such as relational values may be introduced as a third category, or entirely separate paradigm, to instrumental and intrinsic value (Gilliand, 2021), multiplying potential incompatibilities[75]. Some have also argued that intrinsic and instrumental modes of valuation should be kept distinct: ‘reduction of intrinsic value to instrumental terms demeans and trivializes it, giving a counterintuitive advantage to (instrumental) resource exploitation by turning nature preservation into a peculiar, and largely indefensible, special case of resource exploitation and consumption. Maintaining the distinction between intrinsic and instrumental value, in contrast, allows us to set certain things aside and exempt them from use.' (Hargrove, 1992, p.199). The basic idea here is that *use* and *appreciation* are at odds, and so that these modes of valuation are incompatible with one another (Efstathiou and Myskja, 2019).

Others however have noted connections between intrinsic and instrumental value (Efstathiou and Myskja, 2019), such as the dependence of intrinsic value on instrumental value (as in when an object is intrinsically valuable on account of its appearance or flavour) (Kagan, 1998), or the existence of forms of value with features of both intrinsic and instrumental value, e.g. some versions of relational value (Deplazes-Zemp and Chapman, 2020; Himes and Muraca, 2018), as well as the notions of systemic value (Rolston, 1994) and transformative value (Norton, 1988). Attention to more pragmatic considerations around how value is embedded in activities and experiences (Stephens, 2021), including in the practice of science itself (Dussauge, Helgesson and Lee, 2015b), can help with reappraising seemingly intractable debates by exploring the role of different contexts in valuation practices, and unearthing nuances in and therefore enriching the relevant concepts (Centemeri, 2015). It is these accounts I build on here, looking for both the tensions within and between these modes of valuation but also the areas they overlap (Heuts and Mol, 2013).

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[75] Although sometimes they are seen as occupying space between intrinsic and instrumental value (Himes and Muraca, 2018).

3. Value(s) in practice(s)

These debates and definitions discussed above were not developed within the context of coral science. The term ‘intrinsic value’ and the various concepts associated with this are regularly employed by coral scientists. Likewise, ecosystem services and instrumental modes of valuation are also often employed. This is surprising, particularly if the criticisms around the impracticality of intrinsic value, the reductionism and over-instrumentalism of ecosystem services, and their mutual incompatibility, are true. So how are these notions being used in practice in coral science?

Supporters of instrumental value have previously argued that this mode of valuation is much richer than generally appreciated, permitting a wide range of values of biota to be articulated (Maguire and Justus, 2008). I aim to show this is true also of intrinsic value and ecosystem services, and that they are best conceived of as compatible if partially distinct clusters of ways of valuing the environment. Interviews with coral scientists, and exploration of coral science literature, can help clarify this situation. Are coral scientists using ES reluctantly, e.g. as a communication tool for specific audiences (like policymakers) or are they using them because they think they capture coral reef value well? How does intrinsic value get used in practice? How do these two relate?

Based on analysis of interview data and coral science literature, I identify and explore four broad themes in discussions of the value of coral reefs which straddle both intrinsic value and ecosystem services:

1. Non-anthropocentric value
2. Non-instrumental value
3. Non-measurable or intangible value
4. Non-fungible value

These themes all relate in some way to the various senses of intrinsic value introduced above, and despite sounding contrary to many of the features of ecosystem service value, overlap with this too in interesting ways. This list does not comprise an exhaustive account of different modes of valuation in coral science, or even in the interviews conducted, but simply an examination of four prominent themes which offer connections between intrinsic value and ecosystem services. In interviews I asked explicitly about ecosystem services but not about intrinsic value. As a result, many of the quotes here do not mention intrinsic value explicitly, but instead invoke associations with the different senses of intrinsic value outlined earlier.

Here are two typical extracts about the value of reefs which emerged from conversations about the suitability of the ecosystem service label:

Quote 65

> "Of course, the oceans would be vastly less productive, there'd be less fish habitats. So fish would have less areas to breed. We'd lose the diversity of organisms, which goes back to that more traditional conservation concern of the beauty of wildlife and diversity for its own intrinsic value, that would go - it's already gone for many reefs. So our spirit as humans is diminished from it. 1008

Quote 66

> “The other one that has sort of, has stayed with me for a while since I heard it was the Immanuel Kant quote, I’ve forgotten the exact quote, and I'm probably going to absolutely butcher it. But he says something like ‘everything has either a price or a dignity’, or ‘either a value or a dignity’ or something, and that which admits to no value has dignity. Do you know the quote? … And if you try and give something a value, you strip it of its dignity, no matter how big that value is, and **reefs would be better to be thought of as priceless with dignity** rather than monetized.” 1003

The key theme running through these quotes is of the importance some element of the reef (or the entire reef) has for its own sake. The first quote mentions intrinsic value explicitly, with diversity having its ‘own intrinsic value’. The second quote talks of reefs possessing a sort of invaluable quality described as ‘dignity’, which again fits with the way intrinsic value is often articulated, including with specific reference to Kant, a key influence on intrinsic value discussion in environmental ethics (Batavia and Nelson, 2017). Each also invokes concerns which relate to ecosystem service-like formulations of value too however: productivity and the provision of wellbeing (albeit to fish) in the first quote; and the stark contrast of prices and dignity in the two (which exemplifies the kind of incompatibility often posited between these two modes of valuation).

Being able to articulate value in a range of terms, beyond human-centred or narrow instrumental concepts, but also beyond inert and ineffable formulations of intrinsic value, was clearly important to interviewees, and was a recurring part of interviews. The cluster of concepts used to do this have interesting connections to one another, and to the senses of each of these modes of valuation invoked in theoretical literature, which I explore at greater length here. Ecosystem services, intrinsic value, and related concepts such as ecosystem functions, all act in this context as *boundary objects*, that is, devices which enable work and communication to take place across disciplines (Star, 2010; Steger et al., 2018; Ainscough et al., 2019), by enabling discussion and articulation of the important features of reefs for various purposes. They do this by maintaining a vague overarching identity which is then tailored to specific uses by different communities. Each of these modes of valuation thereby allows for a wider range of value relations to be articulated than might be supposed from arguments made by critics (Star, 2010; Steger et al., 2018; Ainscough et al., 2019; Schröter et al., 2014). This opens up the possibility of compatibility between even the starkly opposed worlds of intrinsic and instrumental (and ecosystem service) value.

Throughout these conversations, the value invoked is never entirely unrelated to the connections between organisms, nor entirely reducible to connections with humans. Instead, it was tied up in multiple concerns: other organisms, beauty, happiness, the human spirit, dignity. These connections point to a much deeper and more nuanced conceptual landscape at work when discussing intrinsic value than simply objective value or value ‘for its own sake’, likewise for ecosystem services, them not being simply the material contribution of nature to human wellbeing. I explore the rich usage of these modes of valuation and the connections between them via the four themes I have highlighted, starting with non-anthropocentric value.

3.1 Non-anthropocentric value and ecosystem functions

Non-anthropocentric value is, in this context and broadly speaking, the idea that reefs have value beyond their importance for humans (Hargrove, 1992). Such a meaning is commonly discussed under the guise of objective value, i.e. the idea that intrinsic value is the importance of some entity regardless of how it is valued in the minds of relevant valuers (O’Neill, 1992). I have already expressed some of the problems with this formulation earlier in the thesis, namely that it ignores swathes of value which are relative to living entities, but which do not simply exist in their minds, and ignores the complexity of objectivity and subjectivity (Douglas, 2004b; Daston and Galison, 1992).

Interestingly, *objective value* may sometimes include value which is indexed to non-humans, including instrumental value. Intrinsic value may therefore be used to describe the benefit something provides for a non-human organism, as in Kenter et al.'s notion of articulated intrinsic value, which involves value relevant to the lives of non-human organisms, e.g. sunlight as good for algae, or as in formulations which treat intrinsic value as related to health and integrity of non-human organisms, or ecosystems (Farber, Costanza and Wilson, 2002, p.376; Connor and Kenter, 2019, p.1252). These cases include a kind of instrumental value – often seen as diametrically opposed to intrinsic value - but *instrumental for non-humans*. This is a common enough way to describe the value of reefs too:

Quote 67

> "Yeah, so for me, ecosystem function is what an ecosystem does, does for people, does for the communities that live on the reef. … But then, of course, you've got the kind of people and coral reef side of it. So coral reefs provide food for people, fishing, local communities in really remote areas, they rely on the fish and coral reef to survive. And then you've got things like tourism as well, that all bring money to people, as well as the coral reef ecosystem functioning within itself as an ecosystem. So the live coral is kind of the big thing when it comes to coral reef ecosystems. Coral provide structure, which means it can support more life, you've got more niches available on the reef, shelter, and it's also food for a lot of organisms as well". 1011

Here, the speaker flips between discussing the instrumental value of the reef for people (providing food, fishing, tourism) and its instrumental value for other reef organisms ('support more life' 'more niches available', 'shelter', 'food for a lot of organisms'). Value is phrased in terms of ecosystem functions, that is, processes within ecosystems which support the ecosystem itself, support processes within the ecosystem or which support a whole range of living things, including, but not limited to, humans (Jax, 2005; Harborne et al., 2006). Functions are defined very broadly in ecology and coral science, for example one analysis arguing for a definition of function with coral science as 'the movement or storage of energy or material within an ecosystem' (Bellwood et al., 2019, p.950), and services as a subset of these (Bellwood et al., 2019; Jax, 2005).

Ecosystem functions were often associated with the good of the whole system, that is, the processes which hold together and maintain the entire ecosystem, and which support the emergence of distinctive features:

Quote 68

> ‘But in the way I think about it … a function is something to do with the inherent way the ecosystem is stitched together, and the way that the community of different animals and plants and organisms on the reef, work together to create a property of the ecosystem that wouldn't be there, if it was just single animals. And so we're talking about things, you know, an ecosystem function might be like herbivory, or bioerosion, calcification, the respiration/photosynthesis balance, that sort of thing. And I think some of those functions are ecosystem services as well, because I think ecosystem services are where things that ecosystem does … provides benefit to people basically.’ 1003

Quote 69

> ‘There's the ecological functions, which are sort of coastal engineering, if you like, you know … in the same way that forest trees, you know, create a forest, and that creates a habitat for birds and all the rest of it, and then birds poop in the forest. And, you know, so **they're ecological functions where everything aids each other, so those are all important. So it generates biodiversity, so the biodiversity that you've got on reefs is in itself an intrinsic value, I think.’** 1010

Here, there are overlaps visible with one of the traditional versions of intrinsic value: reefs have a form of value which is linked to their nature as a whole living system which functions ‘within itself as an ecosystem’. This value is connected to the properties of the ecosystem which are to do with how it is organised, and which goes beyond the single animals living there, which ‘wouldn’t be there’ otherwise. ‘Everything aids each other’, ‘is stitched together’ and works together in a way which produces a shared habitat, and produces biodiversity and an intrinsically valuable ecosystem. Functions are also seen as processes which benefit non-human organisms: ‘creates habitat for birds’, ‘aids each other’, ‘more niches available’, ‘food for lots of organisms’. Intrinsic value and instrumental value are fused here in discussion of benefits of ecological processes for non-human organisms and ecosystems.

These formulations of value are closely related to what has been called ‘strongly objective’ intrinsic value, i.e. value which is independent of human valuation and related to the capacity of a system to have something be good for it (O’Neill, 1992; Connor and Kenter, 2019)[76]. When the ecosystem or parts of it (e.g. fish) are considered as beneficiaries, these entities are being considered

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[76] Note that there may still be human values involved here in picking out the relevant functions and entities, as with discussions of epistemic anthropocentrism (Himes and Muraca, 2018) and values in science (Elliott, 2018). The non-anthropocentric value is in terms of the beneficiaries being considered. I discuss incorporating non-human values into epistemic processes in the next chapter.

to have goods of their own, and a kind of intrinsic value is being articulated. Ecosystem functions can be seen as articulating a kind of intrinsic value which is non-anthropocentric, and focuses on the benefits of ecological processes to non-human organisms or ecosystem themselves.

There are also strong connections between functions and services. Services are often considered a overlapping with functions (Jax, 2005), e.g.: ‘[services are] ecological characteristics, functions or processes that directly or indirectly contribute to human wellbeing’ (Costanza et al., 2017). Functions are, in the senses articulated in the last two interview excerpts, processes which benefit some living system, including humans and non-humans. The same distinction was made by others:

Quote 70

> “And then how it [services] relates to function? ... the way I get past all of the academic debates is just like, **it depends what endpoint you're working from**. So if your functions are **ending in your ecological processes**, and that's where you stop your analysis … **then it’s functions as connected to ecological processes**. Your **ecological process can then connect to services and benefits, and therefore functions connects to services and benefits**. **But I don't necessarily think that the term function needs to carry a single, like, meaning**, do you see what I mean? In terms of, like as an academic shorthand, I don't know how useful it is sometimes, because people interpret it in different ways. So yeah, the link between functions and services is basically just like … there are functions that underpin services**. But if you start digging into what that means, then people will argue about what the different functions are, or even a service is, because they're really context specific**, as well” 1006

Here ‘where you stop your analysis’ matters, because it will determine whether you are interested in the benefits a process provides to humans (which is therefore often labelled a service), or whether it benefits non-humans or the ecosystem itself (where it is more likely to be labelled a function). Both services and functions are acting here as boundary objects (Star, 2010; Steger et al., 2018). Both have ‘context specific’ meanings, and functions specifically are seen as ‘an academic shorthand’ which are ‘interpreted in different ways’. There are overarching vaguer meanings to both terms, which are employed across a range of ecology-related disciplines (Jax, 2005; Bellwood et al., 2019), but used in specific ways in the context of coral science. The result is that two boundary objects, functions and services, are often deployed in coral science to do similar work in close connection with one another. The result is a bleeding together of the kinds of value they are used to express. To return to the quote from earlier:

Quote 71

> “Yeah, so for me, **ecosystem function is what an ecosystem does, does for people, does for the communities that live on the reef**. So my research focuses on the behaviour side of that, and behaviour really does underpin a lot of what goes on, on coral reefs. And if we can understand behaviour … that can scale up and we can learn more about ecosystem function. **But then, of course, you've got the people and coral reef side of it.** So coral reefs provide food for people, fishing, local communities in really remote areas, they rely on the fish and coral reef to survive. **And then you've got things like tourism as well, that all bring money to people, as well as the coral reef ecosystem functioning within itself as an ecosystem**. So the live coral is kind of the big thing when it comes to coral reef ecosystems. **Coral provide structure, which means it can support more life, you've got more niches available on the reef, shelter, and it's also food for a lot of organisms as well**" 1011

Here, ecosystem functions are discussed in very similar terms to ecosystem services, but with the inclusion of non-humans as beneficiaries. We have three kinds of beneficiary: First, ‘what an ecosystem does for people’, which is how ecosystem services are typically defined and deployed (NB this is followed by what ecosystems do ‘for the communities that live on the reef’, without mentioning whether these are human communities). Second, the ‘functioning within itself as an ecosystem’, i.e. the ecosystem as a beneficiary itself. Note the strong connection here with the idea of intrinsic value as value in itself, value beyond human interests, or as applying to a non-human system which has interests (i.e. which things can be good or bad for). Third, the non-human organisms living in the reef who are provided niches, shelter and food. Note again the connection with the non-anthropocentric yet still instrumental senses of intrinsic value. The benefits from these processes are distinguished into the ‘people’ and ‘coral reef side’, i.e. whether beneficiaries are human or not[77], and similar distinctions between functions as ecosystem-facing and services as human-facing are made in coral science literature too (Hughes et al., 2017). But

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[77] Further examples of how functions and services were distinguished: “Well, they're obviously very, very closely tied. So you can't really have one without the other. But you can … abuse one quickly for short term gain”. **1015**

"I think ecosystem services is more of a term that you use when you're considering people. And then ecosystem functions, I would say is something when you're referring to the organisms on the reef, and their role in that coral reef ecosystem" **1011**

“I think the functions of the ecosystem beget the services. So if you have an organism that has to filter feed, the service is it cleans the water.” **1008** nevertheless the function concept does foray strongly into the world of services here.

This is the first theme within which intrinsic and service modes of valuation overlap. Intrinsic value overlaps with functions, and functions with services. This overlap may be a site of further future development, with some authors advocating ‘services to ecosystems’ (Comberti et al., 2015) or arguing that beneficiaries of services may be non-human organisms (Jax, 2005, p.642)[78], which would further increase the non-anthropocentric component of ES and so their overlap with intrinsic value.

It might be argued that this is simply confusion of terms however, and that functions and services, properly defined, do not overlap. But this is to ignore the purpose of this investigation, which is not to see how they are ‘properly defined’ – as abstract forms of value - but how they are employed in practice and the extent to which they represent compatible modes of valuing the environment, as with other studies of valuation in practice (Heuts and Mol, 2013).

3.2 Non-instrumental value

Another very common formulation of intrinsic value is as non-instrumental value, that is, as value which is explicitly not reducible to simply providing a benefit for some entity, often specifically humans (Connor and Kenter, 2019; O’Neill, 1992). This type of value is again commonly invoked in the context of coral science, often in opposition to instrumental notions such as ecosystem services:

Quote 72

> “And yes, you know, the aesthetic value, and for me that, because I grew up scuba diving, and looking at the reefs, and thinking that life is worth living because diving is so amazing. I always think that, you know, **the existence of coral reefs, just because they exist is important by itself**. Because just for us to be happy.” 1025

Quote 73

> “and I have my favourite corals as well. I have several corals that I get really excited when I, when I [see] them. …

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[78] One participant did use the term service in this way, in the context of cleaner fish providing parasite removal services to other marine organisms, which seems to be used in this way in literature on the topic too (Cardoso et al., 2020; Mills and Côté, 2010, p.3617).

> **I have two that I really like to see**, one is the *Dendrogyna cylindrus*, which is the pillar coral. … **So I really like this species** but now it's almost impossible to find in the field. **Another species that I really like a lot is *Mussa angulosa***, which is solitary coral, but it's like a very fleshy coral. Corals are a... if you see, they have a very thin layer of tissue and it's basically rock, so you touch them, they are kind of hard, just with a very thin layer of tissue. However this Mussa is very fleshy, it's like two centimetres of tissue, so it's, it seems, **it's a nice coral I like it**." 1021

Quote 74

> "[discussing what they wish more people knew about deep sea corals] … And just yeah, I guess appreciate the rawness and the, you know, it's pure wilderness really, in a way that is... you know, we still know so little about what's happening on the sea floor. I just wish people would be able to go and see it. **That's yeah, a really basic thing, just that they exist and be able to go and see them.** You know, when people hold a coral in their hands, they're already like, oh, wow, this is really cool. But it's always dead [laughs], because it's a coral skeleton." 1024

It is this notion of intrinsic which is invoked in the traditional 'value for its own sake' or 'end in itself' formulation. As in the quotes above, this formulation can be somewhat ineffable: 'just because they exist is important by itself', 'it's a nice coral I like it', 'just that they exist and be able to go and see them'[79]. It relates primarily to the existence of the entity and the nature of the entity, beyond what it does for humans or other organisms. The ideas of being happy that something simply exists, or of having favourite corals, or of seeing or holding a coral and thinking it's cool, all latch on to a kind of intrinsic value centred around not what the corals can do for us, but simply the kinds of things they are, i.e. living beings of a certain type.

This kind of value is often associated with non-anthropocentric formulations of intrinsic value, as discussed in the previous section. But it can also be anthropocentric in different ways: in a basic sense, we might value the mere existence of a coral, which adds a human element to the value being described here. Other forms of non-instrumental but anthropocentric valuation have been put forward under the label of 'relational values', which overlap with intrinsic and

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[79] Ineffable value could have been another theme explored here, although space does not permit it. One participant expressed this in terms of there needing to be no justification in order to protect nature, analogising with the shock felt at seeing someone stamp on a flower:

'There's no justification for why that's something that we shouldn't do. And I don't think we should try to justify it, I don't think you should sort of say that flower's, you know, protected by this law or that, whatever it may be. I don't think that's the point. I think it's just, you shouldn't do that. And if kids shouldn't stamp on those flowers, humans shouldn't impact ecosystems for the same reason.' 1010.

instrumental modes of valuation (Connor and Kenter, 2019; Chan et al., 2016), for example a cultural relationship between humans and corals - as with liking specific coral - which isn't simply instrumental but is still very much derived from human attitudes and practices.

As the modes of valuation above are fleshed out, they often do bring in to play outward-facing features of the entities in question: the speaker above likes *Mussa angulosa* because it is extra fleshy compared to other coral (so a kind of aesthetic appreciation or uniqueness driving their preference for it); others invoke the experience of looking at reefs, which makes them happy or gives them a sense of the wildness and rawness of nature (a kind of aesthetic or affective relation). It becomes clearer here that intrinsic value is not an island. It often connects deeply to the instrumental properties of the entities in question, despite itself sometimes being explicitly non-instrumental in its formulation. This relationship has been recognised in other cases: Kagan gives examples of the intrinsic value of the skill of fine cooking being based in part on the production of excellent food (an instrumental feature of the skill), or the intrinsic value of a racing car being based on its sophisticated design and capacities (again, an instrumental feature of the entity) (Kagan, 1998). So intrinsic value may be rooted in instrumental value, an inversion of the typical thesis in environmental ethics (that intrinsic value begets instrumental) (O'Neill, 1992).

From the other side, ecosystem services also overlap with intrinsic value explicitly through the idea of existence value, which denotes the value people gain from simply knowing something exists (Davidson, 2013). This type of value was also discussed in interviews:

Quote 75

> "It's just often the, that existence value really matters to people, actually. … [referring to a study conducted] … 1000s of people [were] selected by a polling company in … Norway, and Scotland and Canada ... And we were quite cynical, as scientists, we thought people really wouldn't give a damn, wouldn't care [about cold water reefs]. And they might, when they're told about it, be a bit interested. But when asked what their willingness to pay was for conservation, and I know, there's issues around that science as well... But we asked the questions, the answers that came back, were that people prioritize existence values and bequest values, you know, over and above anything else, they were very skeptical of fisheries management." 1019

The point here is that existence value, i.e. the benefits people derive from simply knowing reefs exist, can form a major part of ecosystem service assessments, in this case on cold water reefs (where human subsistence concerns are less relevant). In this case the instrumental value of the ecosystem service being measured depended in part on the existence of the reef for its own sake, i.e. something typically associated with intrinsic value. In this case, intrinsic and instrumental value are blurred, with existence value relating to both the simple existence of an entity, but also the benefit the existence has for other entities (Batavia and Nelson, 2017). The value here is in a sense instrumental, but in a way distinct to valuing processes such as fishing or tourism, as the benefits are derived from simply the existence (and not any further specified activities) of the entity. In this way ecosystem services blur into intrinsic value (Davidson, 2013).

There is something more fundamental driving this blurring, which is the porosity of the instrumental/intrinsic distinction. There are other ways to see this porosity beyond existence value. Intrinsic value is often justified in terms of historical uniqueness (Katz, 2007) (discussed in a quote presented shortly, with loss of reefs described as 'losing a moment in history'). The same is true of other properties of reefs: their diversity, beauty, structural complexity, productivity, busyness, vibrancy[80]. These may be invoked as features of healthy reefs (in certain contexts), and are related to their value for humans, for other organisms, and for themselves. They are both unique and human-independent features of the reefs but also part of the huge benefits they provide humans. This is not to say that healthy reefs will always be the most instrumentally valuable, but simply to say that many of the valuable features of reefs have both intrinsic and instrumental aspects. Aesthetic value, for example, may have connections to the kind of environments we tend to think are safe for us to exist in – as discussed in chapter two - and so intangible concerns like beauty may have

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[80] This recalls discussions of healthy reefs earlier in the thesis. Many of the features of a healthy reef are associated both with intrinsic and instrumental modes of valuation:

"I think what they have in common is that they are diverse, that life is abundant. And these are all relative compared to other ecosystems. So high abundance, high diversity. And just in a not very scientific way, just a hell of a lot going on in a very small space, you know, a lot of different animals, a lot of different shapes, a lot of different sizes, a lot of different colours, a lot of different behaviours, you know, within like a meter cubed of water, you can see animals using the habitat and … they're just using lots and lots of different ecological niches in that habitat in lots of very clever and intricate ways" 1003 connections to more traditional and tangible instrumental concerns (Haas et al., 2015).

So even when intrinsic value is explicitly defined as non-instrumental value – which would seem to be when it is most starkly opposed to instrumental value – there are still overlaps and connections between the two. Non-instrumental value may be based on instrumental value, or may produce derived instrumental forms of value, such as ‘existence value’ in ecosystem services, which describes the benefits humans derive from simply knowing something (e.g. a coral) exists. This is both instrumental (it relates to benefit to other entities) and non-instrumental (it does not involve using the coral for something). This mode of valuation is part of the cluster of modes associated with intrinsic value, along with other modes such as referring to the value of less tangible or measurable things, which nevertheless may still be instrumental, and related to ecosystem services.

3.3 Intangible and non-measurable value

Less explicitly involved in analyses of intrinsic value are the senses in which it simply refers to intangible or hard to measure forms of value. These forms of value may be instrumental or anthropocentric. This sense is invoked implicitly quite often however, particularly in the strong association intrinsic value has with aesthetics and beauty, and with the idea of infinite or indefinable value (McCauley, 2006b; Rolston, 1982, p.126; Efstathiou and Myskja, 2019, p.415; Rolston, 1991, p.13). This intangible or hard-to-measure sense of intrinsic value was also commonly invoked in conversations about reef value:

> *Quote 76*
>
> ‘for me there is two very broad reasons why coral reefs are sort of valuable. The first is basically that they're beautiful. And the second is basically that they're valuable for, you know, stuff like fishing and protecting people's houses, from storms, and all that sort of thing. … I think if we were to lose reefs tomorrow ... I think we'd actually lose the beauty faster than we lost the value, because I think the beauty would just be gone. And that would be a moment in history that we could never get back. … So I think, in that sense, the pragmatic value of reefs, probably, I sort of hesitate to say it because it sounds a bit like you being a bad guy, but I think it probably isn't irreplaceable, in the same way that the slightly less measurable beauty of a reef probably is irreplaceable.’ 1003

In this quote, the speaker typologises reef value into two categories: roughly speaking, beauty and usefulness. This then broadly tracks the kind of distinction often made between intrinsic and instrumental value, with one tied to the ‘less measurable' nature of the system and the other tied to the benefits it provides humans 'pragmatic[ally]'. This is another area for overlap between intrinsic and ecosystem service value. Neither of these forms is seen as isolated from humans. The beauty being described is of great value to humans, is apprehended by them, and depends (in part) on human relations to the reef, including our sensory systems, perceptions and knowledge of nature, perception of colour and complexity, social norms, and our biological and ecological nature (Haas et al., 2015; Vercelloni et al., 2018, pp.8–9). That external valuers are often a key part of the emergence of intrinsic value is something recognised in well-developed subjective and objective theories of intrinsic value (such as those of J Baird Callicott and Homes Rolston) (Gilliand, 2021, p.722).

So the intangible value being described here - in terms associated with the intrinsic modes of valuation - also invokes instrumental concerns, in that it provides a clear benefit to the observer, namely aesthetic enjoyment. The key feature of this expression of value is not that it is non-instrumental, but that it is intangible, hard to measure, and difficult to replace (I return to replacement shortly). This theme was present in other interviews too. Returning to the quote from earlier:

Quote 77

> "And yes, you know, the aesthetic value, and for me, that, because I grew up scuba diving, and looking at the reefs, and thinking that life is worth living because diving is so amazing. I always think that, you know, the existence of coral reefs, just because they exist is important by itself. Because just for us to be happy." 1025

Again, here we see a flipping back and forward between value which is explicitly related to the benefits reefs provide to humans (aesthetic enjoyment, happiness) and value which is simply connected to the existence of reefs. Again, at least some elements of this value are instrumental and related to humans, but in less tangible and measurable ways than other forms. Other interviewees made the connection to intrinsic value and ecosystem services explicit:

Quote 78

> "[on losing coral reefs] … Of course, the oceans would be vastly less productive, there'd be less fish habitats. So fish would have less areas to breed.

> **We'd lose the diversity of organisms, which goes back to that more traditional conservation concern of the beauty of wildlife and diversity for its own intrinsic value**, that would go - it's already gone for many reefs**. So our spirit as humans is diminished from it**.” 1008

Quote 79

> “…recently people have looked into [it], and it seems what people value the most actually, - like the general public, that are not like surviving off the protein from the reefs - **is aesthetics as an ecosystem service**. There's some interesting research coming out of the Great Barrier Reef, that at the end of the day, that is the one thing that people care the most about… **that it looks pretty**, **and that they get that from the reef**. " 1007

In the first of these quotes, beauty and diversity are tied to the intrinsic value of wildlife, but also to ‘our spirit as humans’. By losing coral reefs, the speaker argues, we lose something valuable for various reasons: because it is biologically diverse (which has value in itself, i.e. intrinsically (Soulé, 1985; Callicott, Crowder and Mumford, 1999)), but also because it is beautiful, and because it has a connection to our spirit as humans, i.e. our ways of life and co-existence with it as living beings. Disrupting and destroying those systems therefore upsets the value of the larger human-reef system in which many people find themselves. These senses of value are connected by their intangibility and immeasurability, and so are associated with intrinsic modes of valuation despite being partly instrumental. Biodiversity is often discussed in such simultaneously intrinsic and instrumental guises, with strong dependencies between the two (Callicott, Crowder and Mumford, 1999; Schröter et al., 2014; Helmreich, 2009, pp.110–111, 129). In the second quote, aesthetic value is associated directly with ecosystem services and things that people ‘get from the reef’, a recognition of the instrumental nature of reef beauty, despite it being somewhat intangible. This intangible and hard to measure value therefore tracks back and forth between intrinsic and instrumental (and ecosystem service) modes of valuation.

Beyond beauty and diversity, other valuable features of reefs fit this version pattern too:

Quote 80

> ‘You know, in terms of biodiversity alone, I mean, it's referred to as the rainforest of the sea, which comes with all the unknowns that you can't even put a number on, because that is the intrinsic value of the science that's yet to be discovered.’ 1005

Here, is it the unknown features of the system which ‘you can’t put a number on’ that are tied to its intrinsic value. Intrinsic value once again relates to the intangibility and immeasurability of the features being discussed. These unmeasured features may well be instrumentally or anthropocentrically important, but they are also difficult to articulate and hard to measure, so are discussed in the intrinsic mode of valuation.

Each of these cases is associated with intrinsic value for reasons which are not explicitly opposed to instrumental value. Aesthetic value, for example, is less tangible or easily measured than other forms of instrumental value, and is instrumental in a distinctly non-rivalrous (to use economic parlance) way, i.e. aesthetic value (of this sort) is not destroyed during consumption by one actor, unlike e.g. food. Because of this difference, aesthetic value is often not lumped in with instrumental value (which may often mean rivalrous instrumental value), but considered as part of the value of an entity in itself or for its own sake. This is compounded by the comparative lack of attention from scientists to the beauty of ecosystems:

Quote 81

> “It's not only reefs, but reefs are in the forefront, I think. And it has captured imaginations because of… well because of their beauty, and that the whole side of ethics, of sort of… someone said to me once, why do scientists sort of never bother about the beauty of a place? And I can't really think of an answer why. But I guess that's what draws us to coral reefs, rather than choosing to dive on a seagrass bed, if you are recreational holiday diver.” 1017

Aesthetic value of reefs is not seen as part of the typical professional purview of coral reef scientists, another reason why it is often related to the cluster of modes of valuation associated with the label *intrinsic*, despite often being expressed in instrumental terms. In the previous quote, beauty is associated with ethics, and when aesthetic value is incorporated into a more tangible form it is through the choices of recreational divers, i.e., through something amenable to systematic assessments of ecosystem services, which makes it easily measurable and tangible. Other quotes picked up on this too:

Quote 82

> ‘And I think some functions lead to services. So for instance, if you can consider diversity as a function, then I think that leads to the service that reefs are visually very beautiful and interesting, and therefore you can make money out of you know, making tourists pay to see them.’ 1003

The same value relation (the aesthetic or spiritual or ethical value of a reef for a given person) can be discussed in a more intrinsic way, i.e. as an intangible and somewhat ineffable quality of the reef, or it can be incorporated into instrumental-style assessments by finding metrics which correlate with it. If standardised beauty metrics are produced, making it more tangible, beauty may come to be less associated with intrinsic value[81]. As the primary quantitative way beauty is currently measured is through ecosystem service valuation and monetary estimates associated with this, the result is that beauty is considered either intangible or unmeasurable (and so a form of intrinsic value) or is reduced to the benefits to tourism or recreation (and so associated with ecosystem services).

Many developments in the ecosystem services literature have allowed for even more diverse forms of intangible and hard to measure value to be recognised and described in service terms, expanding even further the overlap with intrinsic modes of valuation. So-called ‘cultural ecosystem services’ allow for drawing in of less typically economic forms of value and more cultural, social, and intangible forms (Braat, 2018; Steger et al., 2018; Gould, Adams and Vivanco, 2020). Given this, many other intangible features of reef-human relations may cross the intrinsic/ecosystem service divide.

3.4 Non-fungible value and incompatibility

Finally, the value of reefs is often expressed in non-substitutable or non-fungible terms[82], i.e. in terms which express that valuable features of reefs cannot be easily replaced once lost. This sense is strongly associated with intrinsic value: intrinsically valuable entities are often described as those which cannot be easily replaced like-for-like, or which do not have equivalents (Jax et al., 2013; Baard, 2019; Muraca, 2011), including in the Kant quote discussed earlier about price and dignity.

This mode of valuation has been invoked throughout many of the quotes explored so far in this chapter. The participant from the earlier quote (Quote 76)

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[81] See Haas et al.(2015) for an example of this, where machine learning is uses to assess reef beauty. Others have used virtual reality headsets to do a similar thing (Vercelloni et al., 2018).

[82] I use the term fungible here because it has a stronger emphasis on entities having the same value, not simply being substitutable.

about losing a moment in history articulated this beautifully. Below is an expanded version of the excerpt:

Quote 83

> ‘I think we'd actually lose the beauty faster than we lost the value, because I think the beauty would just be gone. **And that would be a moment in history that we could never get back**. Because sure … like a shallow tropical sea, it's never going to be an empty environment, there's just too much energy there. **But if we were to lose all the inhabitants of the reef, no matter what else cropped up in its place, you know, you've burned the Mona Lisa, you can paint another painting if you want, but it's not going to be the Mona Lisa is it?** Like it's going to be different. Whereas I think the difference with the value is that I think it is feasible to think that actually, reefs might be replaced by something else that have equal value in terms of fishing output, or in terms of coastal defence, or in some, you know, because from a purely pragmatic approach … there's papers out there that show actually, a degraded reef, if you fish it in the right way, can have a similar fisheries output value [to] a healthy reef. … you can imagine, there's manmade coastal defences, or maybe in some areas, you can plant some other type of coral or some other organism that dissipates wave energy in a similar way to a coral. So I think, in that sense, the pragmatic value of reefs, probably, I sort of hesitate to say it because it sounds a bit like you being a bad guy, but I think it probably isn't irreplaceable, in the same way **that the slightly less measurable beauty of a reef probably is irreplaceable**. Does that make sense?’ 1003

They also returned to the Kant quote they discussed earlier in the interview, to make the same point:

Quote 84

> “That tangible, measurable value starts to … part of that Kant quote is a … there's a little sub phrase, isn't there: admitting to an equivalent, I think, isn't it? It's like that which admits to a price admits to having an equivalent, but that which admits to no equivalent, has a dignity. 1003

Here, replaceability comes to the fore. In the typology introduced earlier (Quote 76) by this participant between beauty and use, the ‘beauty’ side is associated with irreplaceability, whereas the ‘use’ side is replaceable. We can get back similar fisheries output, or wave protection (albeit at much higher costs perhaps), but if we lose the reef, we ‘burn the Mona Lisa’ and a replacement isn’t going to be the same. We lose a moment in history, which has no equivalent. This is an important and abiding use of intrinsic which crops up in debates and reformulations of the concept (Katz, 2007; Himes and Muraca, 2018; Hargrove, 1992).

The quote above draws many of the other senses of value discussed here together. Intangible and immeasurable value is explicitly related to the irreplaceable aspects of reefs ‘the slightly less measurable beauty of a reef probably is irreplaceable’, and the tangible and measurable sides start to admit of equivalents. Non-anthropocentric and non-instrumental value are raised too: we lose ‘all of the inhabitants of the reef’ no matter if their replacements provide the same outputs for us. The entities described are considered unique to some extent, and so cannot be replaced. As with lab animal cases, the affective relations built up between coral researchers and their subjects may be associated with researchers recognising that these organisms have their own unique histories and lives, and are individuals and subjects in a sense which makes them irreplaceable (Friese, 2019). The impact of this mode of valuation on science is significant: by treating living systems as irreplaceable, they become subject to attempts to preserve them at the expense of other entities, that is, they stop being simply human environments and start being possessors of their own environment[83]. This is why intrinsic value is often opposed to instrumental or ecosystem services, because these latter modes of valuation are often phrased in terms of fungibility and replaceability, whereas some versions of intrinsic value highlight the impossibility of truly replacing the valued entity.

But this is not entirely divorced from the ecosystem service framework. It connects most closely to the cultural ecosystem services subtype, which has been developed in ways which allow for richer forms of value, beyond simple economic concerns, to be examined: cultural, affective, aesthetic, leisure or spiritual value are often the target of these frameworks (Gould, Adams and Vivanco, 2020). Cultural ES studies often have significant cross-disciplinarity, and are a site of conceptual innovation and methodological diversity, including, for example, qualitative valuation techniques (Gould, Adams and Vivanco, 2020). This allows more intangible, hard to measure, non-fungible and non-instrumental forms of value to be articulated, and so offers a site of overlap with intrinsic modes of valuation. More recent developments related to cultural ES take this further, for example the relational values framework allows for better articulation of values which is not fungible but may still be significant to humans, hence offering a site of overlap between intrinsic and instrumental (and

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[83] I return to this theme in the bioacoustics chapter, and develop it in more depth in the final chapter of the thesis.

ecosystem service) modes of valuation (Chan et al., 2016). The Life Framework of Values, recently developed, also allows for articulation of value which may benefit some entity (i.e. is instrumental or anthropocentric) but is still non-fungible (Connor and Kenter, 2019). So even in the case of non-fungibility, which seems like a hallmark of intrinsic value and strongly opposed to ecosystem service logic, connections still occur. Cultural ES and their successor frameworks can be used to describe this value, albeit by straying away from traditional and common senses of ecosystem services.

To sum up then, intrinsic value and ecosystem services are not simply fixed concepts. The same ecosystem process may have significance in many senses, aspects of which can be captured by both intrinsic and instrumental modes of valuation. Processes which benefit humans may also be of benefit to non-humans or the ecosystem itself. Shelter for fish is fishing ground for people. Calcification builds up the reef, providing homes, shelter and protection for fish on the reef and for people on the shore. Biodiversity represents value of reef organisms for what they are, but may also be valued aesthetically, which is instrumentally valuable for humans in both intangible and tangible ways (such as through tourism revenue). Intrinsic and ecosystem service modes of valuation can often capture the same valuable features of the reef and highlight different aspects of them. These modes of valuation represent clusters of concepts which, whilst having strong relations to others in the same cluster, can be employed in ways which deviate from the overarching definition, allowing application to novel circumstances (Star, 2010). This means intrinsic value may avoid some of the charges traditionally levelled against it, as well as presenting a more diverse toolkit for describing value than previously considered. Far from being impractical or inert, and simply a way of asserting that an entity has infinite value and so cannot be subject to cost-benefit analysis, intrinsic value can instead be seen as a mode of valuation which involves considering the various valuable features of an entity which I have outlined here. Ecosystem services too may avoid charges of reductionism or anthropocentrism when employed in more diverse ways, allowing for connections to non-anthropocentric, non-instrumental, intangible, or non-fungible features of reefs, and so connections with intrinsic value too. So where does the incompatibility arise?

4. Compatibility and valuable features

4.1 Compatibility and exhaustiveness

All of this is not to say that there are no differences between intrinsic value and ecosystem services as modes for valuing the environment. Many interviewees did note tensions between them. In the quote raised earlier in the chapter where I first introduced ecosystem services, the interviewee highlighted the 'real dangers' of converting everything into monetary value: the valuation process might prioritise destroying the ecosystem if the proposed replacement is valuable enough; that things like biodiversity and intrinsic value cannot be measured or articulated in economic terms; that reefs shouldn't be thought of as put there to provide value for humans, and that thinking of them in this way severely devalues them (Quote 60). Another participant made a similar argument about compatibility:

Quote 85

> "[ecosystem services] do worry me a bit. Because at the end of the day, and I often talk to students about this, and we debate it … **what's the value of me being able to open the window and breathe? Or have a clean glass of water? There's no value. If I'm dying, I mean, that's infinitely valuable to me.** So the whole thing has those issues." 1019

Whilst there are connections between ecosystem services and intrinsic value - as articulated in the last section - there are also key differences: ecosystem services are considered to be more thoroughly economic, and to often entail conversion into monetary values; to ignore that some things that cannot be replaced like-for-like (i.e. a kind of economic commodity logic); and they tend to highlight value to humans at the expense of other forms of value. They also tend to fail in cases where value is very high or a pre-requisite for human life (as with water and breathing). These tensions between ecosystem services and other forms of value are well noted elsewhere (Schröter et al., 2014). But, if, as I have argued here, ES and intrinsic modes of valuation are employed in more nuanced and overlapping ways, where does their incompatibility stem from?

A key driver of tensions between these modes of valuation is the exhaustiveness of the value descriptions they give. This was articulated explicitly by the following participant:

Quote 86

> “I think the danger is that you… we don't know that economic value properly. There's a lot of unknowns associated with it, a lot of species undescribed, and **we don't want to just pin everything on that value**.” **1015**

The concern here is the exhaustive nature of claims about the value of the environment. We don’t even know the full economic value of a system, let alone the full value in a range of modes of valuation, and relative to all the possible value relations it might have. There are lots of unknowns, so a fully economic valuation is going to miss out on lots of important features, as well as on garnering agreement from people who do not see the known valuable features as readily in economic terms. The problem of crowding out other value systems is recognised in some criticisms of ecosystem services, and is not a criticism of the way it articulates value, but the way it interacts with other ways of articulating value (Raymond et al., 2013).

However, coral reef scientists who support ecosystem services will not see it as an exhaustive valuation of the reef, but one way amongst many of capturing the valuable relations present in reef-human interactions. This came across - in the following discussions about ecosystem services - as a kind of weariness with people taking one mode of valuation to be exhaustive of a reef system:

Quote 87

> "EJ: Um and so are you aware of any of the criticisms that people have levelled at ecosystem services as well?
>
> 1008: Well, you mean, as opposed to nature has its own intrinsic value?
>
> EJ: Yeah.
>
> 1008: Yeah. But come on, let's just get on with it [laughs]. … **I find it desperately boring**. And it's so old fashioned. **Can't we just get over ourselves? Of course, there's value in the beauty of the environment**. There's concern that we won't protect areas that aren't intrinsically of ecosystem value or natural capital asset value. So, there is that disjunct, and the problem with completely valuing ecosystem services and natural capital is that you can offset areas against each other, perhaps. **But I think we need to use both**. I'm not saying you know, eliminate the former. I'm just saying it's also important, really important, to say what wildlife does for us in its better state." 1008

Quote 88

> “Yeah, well… look… I think some criticism of [ecosystem services] is valid. … **I think you can have a bit of both right**? I think you can make the argument that you... that a certain ecosystem has enormous value, both monetary value, both societal value, and also, you know, emotional value and spiritual value or

> whatever really you want. **I don't think they have to be mutually exclusive**."
> 1012

The point here then is the pragmatic viewpoint is not to simply opt for describing reef value in instrumental or ecosystem service terms, as has been supposed in theoretical literature (Maguire and Justus, 2008). Likewise, to truly appreciate nature does not require only discussing intrinsic value (McCauley, 2006b). The pragmatic view presented in these interviews was one which recognises the partial compatibility of these modes of valuation, and that the need to capture and articulate the value of reefs means that both should be used simultaneously. This requires embracing the anthropocentric, instrumental, tangible and fungible features of nature as important, recognising the other important features of environments too, and recognising that they are intertwined. There is a kind of pragmatic pluralism employed here which enables the denial of strict dichotomy between ecosystem services and intrinsic value.

4.2 Valuable features

I have shown so far that on the ground in coral science there is a much more nuanced range of ways to articulate reef value than the dilemma presented at the beginning between a naïve and inert formulation of intrinsic value and a soulless and reductive view of ecosystem services. As such, it should no longer be a mystery why coral scientists do not see ecosystem services simply as a necessary evil. Whilst they *are* seen as a good communication tool, which nevertheless can suffer from the drawbacks of reductionism, commodification, and instrumentalisation, they are also seen as a good way to capture the value of reefs, particularly in terms of human dependence on reef systems. The two faces of ecosystem services outlined in section 2.2 Defining Ecosystem Services') are able to co-exist because ecosystem services do not have a single fixed meaning within coral science. Here we see an oscillation of attitudes described by Braverman, between humans as fundamentally negative impacts on reef systems and humans as able to co-exist with or even positively influence them (Braverman, 2018, p.53). In this case, however, it is oscillation between seeing reefs as systems which ought to be left alone by humans, and reefs as systems which possess a trove of resources for us. ES and intrinsic value are employed by scientists in ways which navigate these two extremes, recognising both our dependence on reefs and our capacity to undermine the features of reefs which are valuable for other reasons.

There is also a sense here in which the specific tools used for articulating that value matter less than might be supposed, given that there is considerable agreement amongst coral scientists about what is actually valuable about the reef. This sentiment was articulated explicitly by one participant:

Quote 89

> **“**Yeah, well, yeah, I do. I use it. Although it's not a term I like... I don’t enjoy the term, I have to say, I'm always a bit nervous of buzzwords. And I get ecosystem services. And I use a term as and when I have to, I don't tend to overuse it. **I just, I like to talk about what we're talking about. Okay. We're talking about a structure, we're talking about habitats. We're talking about a habitat built by one organism that is used by many others. We're talking about a recycling of nutrients**. We're talking about something... this ecosystem goods and services, linking it so strongly... yeah, I... It's a personal thing probably.” 1019

They went on to say:

Quote 90

> ".. I just want to talk about what these things actually are. Okay. Yes. it can be viewed as a service. It can be somehow monetized. Yeah, that's a function. I understand that. But I want to think of the specifics. So my papers don't tend to sort of navel gaze too much about that. I think the important thing... it still remains important to have enough of a reductionist approach that you do indeed understand your system. Because really, unless you do, you don't know what the changes are going to mean. And I think we need to kind of focus on the fact that we've changed the planetary system, so much. … So yes, all the things we like to call services and functions, they are going to change, we’d better understand them fast and know what the changes are going to mean. Do you see what I'm saying?" 1019

Here, the participant expresses frustration with terminology such as services or functions, which is notably not simply frustration with instrumental terminology, given the overlap of functions and intrinsic value I highlighted earlier. The point, they argue, is to talk ‘about what these things actually are’. The same features and value relations can often be portrayed using different frameworks. But broadly speaking, much of the significance of reefs can be captured by either framework, and even more can be captured by using both. Similar discussions have occurred in the environmental values literature, for example in movements to stop describing things in terms of intrinsic or instrumental value, and instead simply indicate whether the value relation being focused on is one where entities can be substituted like-for-like for other things or not (i.e. fungibility)

(Norton and Sanbeg, 2020, p.8). The aim here is to move past the rigidities and distractions of debates around strict types of value, and focus on the specific features of the environments and relations they are embedded in which produce value (Connor and Kenter, 2019; Heuts and Mol, 2013). The solution, then, is to embrace both the instrumental and the intrinsic aspects of value relations simultaneously, or, at least, non-exclusively.

Aiming for purely non-instrumental valuation of the environment is, in an ironic way, anthropocentric, treating human use of the environment as uniquely bad. The whole idea of an intrinsic/instrumental distinction, with a neat moral community of intrinsically valuable entities which rely on external and instrumentally valuable ones (Muraca, 2011), presupposes a neatness which cannot be found in ecosystems. Where our activities stop and those of other organisms start is hard to distinguish. A similar tension runs through the hope/despair oscillations described by Braverman: those who see humans as separate from nature, in the sense that our influence on the environment is uniquely and necessarily bad, will despair at the impact of our activities, and those who see us as part of nature may see less reason to limit those activities in general[84]. But between these is a recognition that we are one type of agent amongst many in the world, and that we have the capacity to influence environments in ways which are not solely negative, giving rise to a deeper more active and hopeful attitude towards our relations to the rest of nature, one where our actions are not doomed to be damaging (Braverman, 2018). In the words of Donna Haraway in the context of lab animals, we can “refuse the choice of 'inviolable animal rights' versus 'human good is more important’” (Haraway, 2009, p.129). The debates across the instrumental/intrinsic dichotomy are based on this idea, that the use of another living entity is either always or never acceptable[85]. But in reality, instrumentalisation is a core feature

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[84] Jan Sapp noted a similar dynamic when coral scientists were faced with surges in the populations of coral-eating starfish: are they unnatural surges which require intervention to remove, or natural ones we should leave alone? Such reasoning presupposes a kind of separation of humans from nature (Sapp, 1999).

[85] There are, I suspect, interesting connections to debates between deontological and consequentialist ethics here too, especially given the Kantian roots of much intrinsic value talk (Batavia and Nelson, 2017) and the utilitarian flavour of much instrumental value talk. A similar move to the one made in this chapter would be to deny a strict dichotomy between deontology and consequentialism, or to adopt situation ethics instead.

of the living world, an undeniable part of the webbed networks of survival and flourishing we find ourselves and reefs embroiled in (Haraway, 2009).

Anthropocentric values are only ‘unsustainable’ and ‘morally inappropriate’ (Batavia and Nelson, 2017) when they are unbridled and taken to be exhaustive of the value of the environment. But to ignore anthropocentric and instrumental valuation is to separate ourselves from the world we inhabit. We can recognise ‘the stunning beauty of the Sistine Chapel’ whilst also appreciating that ‘it keeps the rain out’, then (McCauley, 2006a). What matters is ensuring that the way we interact with nature is not unreasonable, i.e. that our lives amount to *justified* robbery. The value practices of coral scientists demonstrate this, weaving together both intrinsic and instrumental considerations in a way which defies a neat dichotomy between them, but leaves us with an enhanced sense of the value of reefs.

5. Conclusion

It is sometimes argued that instrumental valuation, such as ecosystem services, needlessly reduces the complex web of interdependencies in nature and impoverishes our descriptions of the world (Muraca, 2011). I hope to have shown that in practice, such modes of valuation are deeply intertwined with other considerations, and that coral scientists are employing considerably more nuanced and diverse sets of value concepts than might be supposed from looking at the literature on ecosystem services and intrinsic value. Some of the threat of ecosystem services is, in this case, mitigated from within. Ecosystem services need not be tools of neoliberalism, and can be used against it, for example by considering organisms or ecosystems as beneficiaries. They are not purely economic, nor necessarily reductionist, extractionist, or commodifying, although they can be and are used in this way. They are often anthropocentric and instrumental, but also act as boundary objects to allow for articulation of intangible and non-anthropocentric features of reefs.

Intrinsic value may denote non-anthropocentric, non-instrumental, non-tangible (or hard to measure) and non-fungible value, and each of these themes has connections to and parallels within ecosystem service terms. The seeming incompatibility of the two modes of valuation only holds in limited circumstances, particularly when one framework is taken to be exhaustive of the value of the reef. Recognising the diversity of usages of these terms opens up new opportunities for describing the value relations between nature and people, and shows that these areas are fertile seas for conceptual innovation, something overlooked by critics. It points towards a more complex understanding of value which recognises that many seemingly different value descriptions will capture the same things.

Coral scientists, I have shown here, often refuse the horns of the intrinsic/instrumental dilemma, recognising that organisms must use one another to survive, but this does not make nature devoid of any values besides those linked to usage. Denying the intrinsic/instrumental dilemma, and the connected ideas of fixed and transcendental categories of value, rather than modes of valuation which may overlap with one another, is an important part of recognising and embracing the whole range of values present in reefs and their encounters with humans, and opens up avenues for better understanding value in scientific and ecological contexts. This is in turn important for evaluating policies and interventions related to reefs (Himes and Muraca, 2018). The blurring of the distinction between intrinsic and instrumental value, and of the boundaries between different beneficiaries of coral science, is an important feature of coral science which I return to in the final chapter.

Attending to valuation practices, rather than predetermined concepts, also further opens the door for investigation of the value of nature via interviews, ethnographies and participatory approaches (Norton and Sanbeg, 2020, p.14). But, as I have argued in the first two chapters, the value of the reef system to non-humans is also an important part of this picture. How are non-human perspectives to be incorporated? How can the value of a reef to non-human organisms be judged when economic and sociological methods would be harder or impossible to apply? How can the epistemic anthropocentrism of scientific processes, i.e. that the judgements and knowledge they produce are in some sense human-centred (Himes and Muraca, 2018), allow for non-human perspectives? In the next chapter, I show how some coral science techniques can factor in the value relations relevant to the lives of non-humans, and thereby allow a greater role for non-human valuation in scientific processes (and so in construction of ecological baselines).

Chapter 4 - Science and values in multispecies contexts: the case of coral reef bioacoustics

> "What you see and what you hear depends a great deal on where you are standing. It also depends on what sort of person you are." - C.S. Lewis, The Magician's Nephew (1955).

Abstract

In the previous chapters, I have demonstrated producing and employing a baseline for assessing the health of a reef necessarily requires consideration of how it is valuable, and for whom. This view of reef health requires the inclusion of the values and interests of specific socio-ecological entities in order for a judgement to be made, that is, it entails evaluation of the system from a certain perspective (or set of perspectives). I have discussed how some of this value is perceived from the perspective of coral scientists. But how does this apply to the non-human inhabitants of the reef? Anna Alexandrova's three rules for dealing with values in scientific processes (in human cases) will be a guide here, and I show how methods being developed in coral science (specifically, bioacoustics) can extend these rules to non-human cases, providing a reliable way to integrate the values of diverse socio-ecological actors into the baselining process. This also has a direct connection with work on the role of care in research on animals, where care towards study organisms is an integral part of the science. The overall aim is to show that bioacoustics, and other techniques which take account of the constraints of the environment and contingencies of organism physiology, can help produce theories and concepts which are more responsive to the interests and values of other species, providing more robust and relevant understandings of important phenomena, in this case, noise pollution and ecosystem health.

1. Introduction

In the previous chapters, I argued that there are several ways in which depictions of healthy reef systems and assessments of their health status can vary, and that not all of this variation is considered illegitimate. The core issue is that to understand the health of a reef, or the nature of changes happening to it, requires not just facts about the case, or the history of the system, but also an evaluation of it, which allows for multiple reasonable understandings of reef health. Assessing the reef requires considering it from a certain perspective or set of perspectives. The reef, after all, is a shared system, and changes to it will have different impacts on different forms of life. A healthy reef for some users might be a degraded one for others. But this raises important further questions, namely, which values are incorporated into the baselining process? In the last chapter I showed that a range of valuable features of reefs are considered by coral scientists. But how can non-human value and perspectives be included in this? And does the incorporation of such values threaten the objectivity or reliability of the scientific process, and so of the baselines produced?

This kind of problem – of needing to incorporate values into scientific assessments, and of worries about undermining reliability - is common in situations where health or wellbeing are at stake. Much has been written about it in human, ecological, and medical cases (Alexandrova, 2018; Lackey, 2001; Nelson, 1995; Kingma, 2007; Dupré, 2007)[86]. I have explored some of the ways coral scientists engage with reef value from a primarily human perspective (intrinsic value and ecosystem services). But I have also stressed the importance of non-human residents of the reef. This offers a more specific problem: how can coral science take account of the ways these ecosystems are valuable for non-humans? And how can we be sure that the outcomes of such assessments are reliable, if they depend on taking up specific perspectives? In what follows, I argue that a set of techniques being developed within coral science offers an example of how this can be done, offering a sketch of the kind of socio-ecological procedures which can help ensure that scientific outputs are reliable (because there is oversight and deliberation around which values influence them) and relevant (because they take into account the aspects of the environment which are valuable to humans and other organisms). I focus on two concepts which bioacoustic techniques can be used to assess: reef health, and noise pollution.

Studying non-human perceptual systems can reveal the partial nature of our own perspectives as well as the nature of the partial perspectives of other organisms (Haraway, 1988). The lifeworlds of other organisms can be

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[86] Kingma has an interesting analysis of this in the case of animal health (Kingma, 2020)

integrated into a meta-naturalistic view of the world, where they become a part of nature, not simply the experience of it, and so can tell us more about how it is structured. To take an example from Haraway, flowers which present themselves as the sex organs of bees, or, even more broadly, organisms which disguise themselves as anything, tell us something about how other organisms perceive the world, and about how that relates to our own experience (Osorio and Cuthill, 2015; Haraway, 1988, 2016, p.69). The lifeworld of an organism then is not an unknowable and impenetrable bubble, but something which can be studied and understood, if only partially (Yong, 2022). In studying these, it is possible to discern how environments are valuable for organisms. Like the valuography of the last chapter, here I not only pay attention to values but also to the activities they are associated with, treating them as enacted in specific activities rather than transcendental (Dussauge, Helgesson and Lee, 2015, p.278). Unlike the last chapter however, I focus on how scientific methods allow this to be done with non-human organisms. This has been done elsewhere: observation of the behaviour, evolutionary history and physiology of octopuses has been used to tell rich stories about their inner lives and the ways they interact with and experience the world: see for example Godfrey-Smith's *Other Minds* (2016) or the documentary *My Octopus Teacher* (2020). These stories enable an unpicking of the value relations which the octopus finds (and makes) itself in.

In this case, I look at fish and coral, and how scientific developments offer opportunities for incorporating non-humans (as knowers or perceivers) into social and scientific processes (Stephens, 2021), producing the possibility of more-than-human epistemic communities, including not just diverse social groups but also diverse groups of species (Connor and Kenter, 2019). These lifeforms are relevant to our forms of life in a variety of ways, and insights from them are translated across into human scientific understandings of the world. Anna Tsing offers a striking example of such cross-species valuography in another area: Matsutake mushrooms tend to have different effects on the gustatory systems of people in different cultures, with Japanese people more likely to be attracted by their smell, and Americans repelled by it. This value-laden gustatory relationship stretches into scientific practice in both cultures: Japanese scientists have focused on studying the attractive qualities of the smell for insects, whilst American ones have focused on the repulsive ones (Tsing, 2015). Here, multiple value-laden relationships are traced across species and disciplinary boundaries by paying attention to the way different entities interact in different contexts. Just as the properties of the mushroom and different human minds (and bodies, cultures etc. they are embedded in) produce different value responses and actions in the world, so they do with insects, and with scientists studying them. I offer here a similar tracing of value-laden concepts and practices across reef ecology into reef science, building up a picture of the ways non-human values can be incorporated into coral reef science and the baselines it produces.

2. Coral reef bioacoustics

Put briefly, marine bioacoustics is the study of the interaction of marine life and sound (Montgomery and Radford, 2017)[87]. Coral reef bioacoustics focuses on the organisms found on reefs, typically fish and invertebrates. As briefly discussed in chapter one, bioacoustic methods have been used to better understand (and intervene on) reef systems. The cases I examine here relate largely to reef fish and coral larvae. Both fish and coral have lifecycles which start on reefs (where they are born), then involve a period of floating around in the open ocean whilst young, before returning to a reef to settle down for their adult lives (Gordon et al., 2019; Vermeij et al., 2010). The process of finding a reef to settle down on is not an easy one, involving travelling vast distances, often without reliable visual or chemical cues. This has spurred researchers to examine the ways in which fish and coral do find reefs from the vast open ocean (Vermeij et al., 2010). Sound perception, it turns out, is one such way by which they do this[88], with coral larvae using sound emitted from reefs to orient themselves towards them when swimming, and fish using sound to distinguish between, and preferentially travel towards, certain reef states (Vermeij et al., 2010; Gordon et al., 2019). A sense of the constraints of these environments, and desire to understand how these organisms navigate them was frequently invoked in interviews:

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[87] Sound being ‘propagated vibratory energy’ (Gans, 1992), although this definition isn’t without ambiguities and leaves space for overlap with e.g. touch.

[88] Along with chemical sensing in some cases (Vermeij et al., 2010; Gordon et al., 2019) and magnetic sensing for some fish (Yong, 2022)

Quote 91

> ‘… But they also often can't see very far. And all of them spend half of their life in darkness … unless they're in deep water, in which case it's even longer. So the acoustic world is really critical to the animals that live there. And listening to the reef gives us a window into that into that acoustic world’ 1002

Quote 92

> ‘… think about the life history of these animals, they spend half their life in the dark, they've got really advanced hearing abilities. They live in this chaotic, really busy world where you can never see more than 20 meters. Then you think, oh no, actually, it does sort of make intuitive sense that these animals would be using sound really heavily in their ecology.’ 1003

Quote 93

> ‘Because sound travels better in water than it does in the air. It's dark there, there's no light, which is sometimes also easy to forget, when you're looking at a video where there's big lamps shining, you kind of forget that these animals actually can't see each other, they would feel each other or they could hear each other.’ 1024

Each of these quotes stresses similar points. Seawater is not conducive to sight. Light travels poorly in water compared to sound, which can travel very far and fast indeed[89]. These techniques are designed to capitalise on this, taking account of the physical and ecological properties of the system in question, i.e. the affordances and constraints of the environment[90]. Because these organisms have adapted to these conditions, often over long time periods, they can be used as inspiration to help us better understand things within that environment, i.e. an opportunity for biomimicry (Blasiak et al., 2022). One interviewee made the very explicit the role of biomimicry in this process:

Quote 94

> ‘And the lesson there is not that corals can detect sound and move towards sound, it's that, it's pretty humbling to realize that **if in nature, there is useful information, then given enough time, evolution will find a way of making**

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[89] Whales can communicate thousands of miles using sound in the right conditions (to the point that some have suggested that herds spread across ocean basins may be in constant communication with one another) (Payne and Webb, 1971). Human-derived sound can be detected at the bottom of the Mariana trench, the deepest known point of the ocean, over 10km down (Dziak et al., 2017). The sound of the explosion of dynamite near Australia was once recorded near Bermuda, approx. 12000km away (Payne and Webb, 1971, p.129). Sound travels a few times faster in water than air (Montgomery and Radford, 2017, p.503).

[90] Affordances are what an environment affords an organism, i.e. what it facilitates and allows a living being to do (Chong and Proctor, 2019). Chairs afford sitting. Seawater affords hearing, as sound travels well in water, but not so much seeing, as light is absorbed quickly.

> **use of that information**, no matter how simple the organism, how basic its biology, how basic its sensing systems are, that information is critical.’ 1002

Quote 95

> ‘And so **learning how other animals sense their environment helps us get inside their heads rather than look down on them**. And that's where I think the most exciting discoveries are… one of the phrases we coined with coral reef restoration was learning how to think like a fish. … that's the better way than to think like the fish biologist’ 1002

Acoustic perception offers a deep and detailed insight into the nature of marine systems for two reasons then: it accords with the constraints of the environment, something demonstrated by the range of organisms which have settled on it as a solution for communication in marine settings; and it is also used by a range of organisms in that environment, meaning it offers a window into the presence and activity of these organisms. This means it provides both an effective method of gathering information about the environment (compared to, say, chemical sensing or sight), but also one relevant to the lifeforms there, with many of them producing and detecting noise themselves. It is here that the first inkling that this might be a way of incorporating non-human values appears (‘get inside their heads rather than look down on them’, ‘think like a fish.. that’s the better way than to think like a fish biologist’).

2.1 Mechanisms and metrics

Invertebrates and fish hear through a variety of mechanisms. In some reef organisms this may involve, for example, the movement of their entire body, rather than just a certain part of it, or the use of accelerometer-like devices for detecting movement of particles in their environment, rather than the waves of pressure humans are attuned to (Nedelec et al., 2016). As a result, sensitivity to cues may be very different depending on the specific combination of organism, environment and stimulus.

Looking at the behaviour of reef organisms in response to certain cues is a key feature of this research, which was articulated in the following interview discussion, where the interviewee was describing coral larvae:

Quote 96

> ‘… they can discriminate somehow, the different types of sounds, so that they are attracted by high quality habitat, but not by poor quality habitat. So they obviously don't have a memory of all those different habitats, types of habitat, they don't even have a brain, but somehow they're wired to move in different

> ways when they're stimulated by different types of sound. And a healthy coral reef is a noisy, vibrant, diverse soundscape. Because it's the noise made by all the animals. And the corals, both swim towards it and swim downwards when they hear that sound or experience that sound.' 1002

Here, the participant is explaining how their research shows that coral larvae move preferentially towards certain soundscapes. Fish have been shown to do this too. In at least some cases, this is not just due to the volume of the soundscape, but likely due to specific qualities of the audio, including things like pitch (Gordon et al., 2019; Simpson et al., 2010)[91]. Importantly, this preferential movement is taken (in this context) to reflect aspects of the landscape for the organism swimming towards it, that is, the sounds are used by the organism as reliable cues for the suitability or quality of the habitat[92]. This suitability, according to the interviewee, broadly correlates with what they think of (in this context) as healthy reef systems, i.e. 'noisy, vibrant, diverse' because it reflects a high degree of biodiversity ('the noise made by all the animals'). In that case, the same acoustic indicators can be used by humans to judge the health of a reef system.

2.2 Experiments and observations

Through experiments in the lab and the field, scientists can study the responses these organisms have to changes in their environment. I will draw on a few examples throughout this chapter. First, the use of choice chambers, which are systems for assessing the attractiveness of stimuli, such as sound, for fish and invertebrates. They are tanks suspended in the water (often in-situ at the site being investigated), which enables organisms inside them to swim to one end or another, where they can better hear different stimuli (Simpson et al., 2010, p.1099). This gives an indication of the significance of stimuli for these organisms in terms of how likely they are to swim towards or away from it. A related tool is the patch reef, a small patch made of dead coral rubble, which can be placed underwater and attached to breezeblocks to create a stable and structurally complex habitat for reef organisms (Gordon et al., 2019). By placing

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[91] Fish can be keen discriminators. They may be trained to distinguish quite complex sounds, including to tell the difference between blues and classical music (Chase, 2001). (This means they could presumably also be used to recommend songs based on data about someone's preferences – but don't tell Spotify).

[92] Obviously this process is not fool-proof. Organisms can be trained to swim towards certain sounds preferentially over others (Simpson et al., 2010), which opens the possibility that non-human organisms may sometimes perceive degraded ecosystems as desirable (and suggests that there may be parallels with baselining processes for human and non-human observers).

different stimuli near these, the impact of these stimuli on the attractiveness of the habitat can be judged. These experiments introduce different kinds of sound near to the chambers or patches, and then study how this impacts the species composition of the patches or the distribution of organisms in the chamber. Other experiments can also be conducted by adding different sources of noise to see what impact this has on specific marine organisms. In one case, researchers collected and moored fish embryos on a substrate under the water, monitored them with cameras (which enabled them to see and measure their pulse rates) and then subjected them to different noises, including by driving boats with different engine types (two- and four-stroke) near them (Jain-Schlaepfer et al., 2018). The aim was to understand the impact of specific noises on the fish embryos, in this case looking at possible stress responses to anthropogenic noise. Both types of engines caused heightened pulse rates in the embryos, of a magnitude similar to known stress responses, with the two-stroke producing a stronger effect.

After building up a picture of the impact of different sounds on specific organisms, of the kind of soundscapes preferred by reef organisms, and of the acoustic signals associated with reefs we consider healthy, this can then be used for assessing reef health and changes to the reef system. By deploying sound recording devices near reef systems, scientists have another tool for assessing the health of that system. Different techniques for doing this are now being developed, including metrics for assessing the quality of the sound, for example its volume and various forms of complexity, as well as methods which tie acoustic signals to the presence of certain organisms or amounts of biodiversity (Gordon et al., 2019, 2018; Nedelec et al., 2015, 2016). There are also methods which use machine learning to categorise reefs by how degraded they sound (Williams et al., 2022). The right acoustic signals, for example indicators of the complexity of the soundscape, are taken to be representative of a healthy reef system (Gordon et al., 2018). Traditionally, such judgements have been made via other methods, notably methods which ultimately rely on visual appearance of the reef, as judged by the human eye, sometimes augmented with computer software and sensing or imaging technologies (Jokiel et al., 2015), or chemical sensing to determine the rate at which the reef structure is growing or shrinking (Lange, Perry and Alvarez-Filip, 2020). Not only this, but interventions can be designed which replicate healthy reef noises to draw in fish to specific reefs. Increased fish populations can have positive impacts on reef ecology, opening the door to potential positive feedback loops which improve ecosystem condition (Gordon et al., 2019). Through these methods scientists employ a system of division of perception (Helmreich, 2009, p.43) – a kind of cyborg science (Toon, 2014; Helmreich, 2009, chap.6) – but one which involves and incorporates value relations with and of other lifeforms.

3. Taking account of non-human values

But how does this process of incorporating non-human values into scientific assessments operate, and how reliable is it? Philosopher Anna Alexandrova suggests three rules to ensure that scientific processes take account of value judgements in ways that produce outcomes which are reliable and relevant (Alexandrova, 2018). These rules are as follows:

1. ‘Unearth the value presuppositions in methods and measures’ (Alexandrova, 2018, p.437)

So in the case of reefs, this involves spelling out what a healthy reef looks like and why, detailing the assumptions underlying this, for example, that healthy reefs provide ecosystem services, exhibit certain ecological features, or have high biodiversity (each of which may only be true given a certain perspective, and in specific ecological settings – see chapter two).

2. ‘Check if value presuppositions are invariant to disagreements’ (Alexandrova, 2018, p.438)

i.e. check if disagreements about these value judgements would cause different outcomes to the scientific process. So, for example, if I happen to see economic value as the only important value consideration for reef health, I might characterise it differently to those who consider the intrinsic value or beauty of the reef, or the value of the reef for certain organisms.

3. ‘Consult the relevant parties’ (Alexandrova, 2018, p.439)

In doing so, ensure their values are considered when deciding on which measurement techniques to use, how to characterise the results, and how to treat the system in future. Importantly, this step should include experts who have knowledge about the system, because they are – in some instances –

thereby better placed to understand the value of the system (Alexandrova, 2018, pp.448–449)[93]. This rule is the trickiest to apply to non-humans, given that consulting non-human organisms cannot meaningfully be done in many of the ways used for human cases. Verbal deliberation with a group of reef fish might not get you very far. Douglas (2004a) offers a further fleshing out of how the public can fruitfully influence scientific processes, which I will use to help understand some ways in which non-humans can be consulted in this case.

The intended benefits of following such rules are that doing so allows for values to enter into the scientific process in a way that is as trustworthy as possible, ensuring that values have been subjected to scrutiny and social control in a way that gives the results improved reliability, (Alexandrova, 2018), closely related to what has been called 'procedural objectivity' by Heather Douglas (Douglas, 2004b). This is a socially-oriented understanding of reliability or objectivity, which emphasises that the processes of science can be better trusted by relevant communities when they have been embedded in the right kinds of social context, ensuring they are subject to sufficient oversight. What I offer here is a socio-ecological extension of this, that is, an example of how this kind of procedural objectivity can be obtained in situations where there are multiple stakeholders of different species, thereby offering a socio-ecological sense of objectivity.

Given that many people care about reef ecosystems, and given that they are made up of a great many different lifeforms, it is important to make explicit the living systems which are, and which should be, included in the scientific process, along with the ways in which the system is valuable for them, to weigh up the consequences of including these considerations, and to take steps to maximise the inclusion of these relevant parties. By doing this, we can produce theories which are more reliable (because the value judgements have been considered and processed appropriately), robust (because the resulting theories hold across a range of perspectives), and relevant (because they are indexed to what we care about in the system). I now turn to each of Alexandrova's rules in turn, showing how they can be extended – through bioacoustic techniques – to

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[93] This includes local users of the reef systems, who may be experts about the reef system in many ways too. Exactly who counts as an expert and should be consulted is not an easy question to answer. For more on this question see Wynne (1995) and Ravetz and Funtowicz, (1999).

include not just humans, as Alexandrova intended, but also reef fish and invertebrates, offering a process for considering more-than-human stakeholders in scientific processes, as others have also begun to do (Connor and Kenter, 2019, p.1253). For each case I will employ specific examples taken from interviews and scientific literature.

3.1 Making value judgements explicit

The first of the rules offered by Alexandrova for navigating situations where values play important roles in scientific concepts is to make those value judgements explicit. More specifically, she says, we should ‘unearth the value presuppositions in methods and measures’ (Alexandrova, 2018, p.437). This involves going beyond simply stringing together indicators associated with a phenomenon. What is needed is an outline of what it is that is being investigated, the theories underlying it, and the connections between these and the relevant indicators. In the case of measuring human wellbeing, Alexandrova argues that investigators should make explicit which measurements they take to reflect wellbeing at the start of the process (Alexandrova, 2018, p.347). Bioacoustics offers opportunities for this in the case of coral reef health, both by spelling out the underlying theory of reef health better, and also by spelling out which organisms are to be considered in the process at all, which is important for better understanding reef health but also for the next two rules. Recall also that underlying theories of health were a key source of variation in the reef baselining process, and so making them explicit is important when trying to understand the health of a reef system.

3.1.1 Making value judgements explicit: underlying theories

Bioacoustic techniques can be used to give a more explicit indication of what reef health is taken to be[94]. I have argued in earlier chapters that there is a range of ways to characterise reef health, especially in more abstract cases, and that using different background theories, and choosing different methodologies and indicators, can therefore give quite different outcomes. But bioacoustic techniques can help with this process, as outlined by participants:

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[94] Likewise for other similarly evaluative concepts, e.g. regeneration and degradation (Jones, 2021).

Quote 97

> ‘what we know about the invertebrates probably is that they can direct their movement towards sound. … They can discriminate somehow, the different types of sounds, **so that they are attracted by high quality habitat, but not by poor quality habitat**’ 1002

Quote 98

> ‘…where, you know, the sound from healthy reefs is more attractive than the sound of degraded reefs. So there's something there that larval fish are picking up on, something from the sound of a healthy reef that's more attractive, and is bringing more fish into them than a degraded reef where you don't have as much sound or it's a different type of sound or something that is missing from that degraded reef, and it's not as attractive.’ 1004

In both quotes, a few important concepts are employed: health, habitat quality, and attractiveness. These concepts are treated as overlapping: healthy reefs are more attractive than degraded ones; high quality habitats are attractive ones. Bioacoustics offers practical ways to grapple with and integrate these concepts. Attractiveness for specific organisms becomes something that can be assessed, for example, through choice chambers, which allow scientists to see which stimuli organisms are attracted to (Simpson et al., 2010; Gordon et al., 2019). At the same time, this can be examined in the context of existing methods for understanding reef health, such as visual or chemical surveys, as well as existing knowledge of the kinds of habitats reef organisms usually survive and flourish in.

By integrating these different ways of understanding reef health and related concepts, scientists are better able to assess the reef from the perspective of fish and coral, as well as from the human case, and to produce an understanding of health which includes their perspectives and ours. The integration occurring here includes not just different methodologies or disciplines (Brigandt, 2010), but methodologies which are relevant to specific lifeforms and forms of life. Doing this requires the spelling out of specific features of reef health and relating them to one another, and in doing so produces a multi-species theory of reef health. For example, in the quotes above, health is associated with ‘noisy, vibrant, diverse soundscape[s]’, the presence of a range of animals, the attractiveness of this ecological arrangement to certain species of reef fish and coral, and the detection of certain sorts of audio signatures. Whilst this is far from a full-blown theory of reef health, it does start to make explicit what it is that is being measured in this case, and what it is taken to represent.

3.1.2 Making value judgements explicit: relevant parties

Bioacoustic methods also make explicit which organisms are being considered when assessing reef health. Alexandrova's rules are based around the inclusion of the values of the relevant parties, and so an important precursor to this is to make explicit not only these values but also who counts as a relevant party (Alexandrova, 2018). As I showed in the first two chapters of this thesis, this is a key consideration. Assessments of reef health depend heavily on the perspective being considered, i.e. which organisms are being included (and which environmental features relevant to them are included too). Different reef states will not have the same significance for different organisms. Coral bioacoustics helps with this in two related ways, discussed in the follow excerpt:

Quote 99

> 'So if, if we want to study the health of a coral reef … traditionally, people use visual census… so swam around with clipboards and counted things, which is useful, totally. But it is quite different to how animals perceive their environment. … And listening to the reef gives us a window into that acoustic world, **what we find is that the sounds that we detect are often not the fish or the invertebrates that we count**. **So it gives us then a way of surveying the cryptic animals, the infauna, the things that live inside the reef that you never see. And the nocturnal animals. So it's a really good complement for visual census.'** 1002

This might sound like the simple stringing together of different indicators, something which Alexandrova argues is not to properly deal with multiple evaluative perspectives. But there are important differences here. These methods are complementary, with acoustics bringing to the fore things which are not visible ('gives us then a way of surveying … things … that you never see'), particularly things like nocturnal or hidden organisms. Here the integration of different methodologies can be used to tackle a specific problem (Brigandt, 2010, 2013), namely how to best survey the state of a reef, and use that to characterise its health status. The differences between these methodologies are important, each providing separate ways to draw inferences about the reef, and provide distinct insights and underlying justifications for their reliability, helping them reinforce one another (Massimi, 2022).

Combining these methods for detecting resident organisms offers a more comprehensive picture of the makeup of the reef, which is an important step in making the value judgements involved in characterisations of reef health explicit. In order to even begin considering these organisms when assessing reef health, we must know they exist. This is one of the reasons why, on top of facts being value-laden, values are *fact-laden* too, and so experts in matters of fact may have some claim to expertise in the values related to those facts (Alexandrova, 2018, p.431; Gorski, 2013, p.543). By using methods which are sensitive to the constraints of the environment, and which are used by many resident organisms, it is easier to get a grasp of which organisms are actually present, and so to decide whether and how to factor them into assessments.

Building on this, bioacoustic methods often involve studying how individuals and species respond to stimuli, for example when trying to work out how coral and fish larvae manage to find reefs and settle on them or how fish respond to different acoustic environments, such as by exposing them to sounds and seeing if this alters their preferences in the future (Simpson et al., 2010); or by investigating whether different types of boat engine have the same impact on their behaviour (Jain-Schlaepfer et al., 2018). The choice of study organism helps further articulate which reef organisms are subject to the most care and attention. Such choices may not be simple – involving various reasons, for example, ecological importance, pre-existing scientific infrastructures, how accessible and amenable they are to investigation, and all of the other considerations which come with choosing experimental organisms (Ankeny and Leonelli, 2020) – but they nevertheless help make clear which entities are subjects of attention and care from coral scientists, and which are not. Experimental organisms are chosen because they are taken to offer insights into some class of organism more broadly, or some specific phenomenon taken to be important (Ankeny and Leonelli, 2011), and so the choice of organisms in investigations into reef health give insights into the organisms and phenomena scientists are concerned with. How these organisms are studied shows the significance they have for the overall socio-ecological arrangements being prioritised by coral scientists, helping show which ones are being explicitly included or excluded in measurements of ecosystem health. The value of the environment for invasive organisms[95], for example, may be excluded, or actively targeted as undermining reef health (see e.g. Diller, Frazer and Jacoby (2014). Meanwhile, the focus on impacts on coral and fish is often justified in terms of their roles in the larger ecosystem, and importance for the reef, demonstrating commitment to a version of reef health based around these entities (Jain-Schlaepfer et al., 2018; Gordon et al., 2019).

By producing a clearer articulation of the underlying theories of reef health, a better understanding of the organisms present, and giving an indication of the degree to which those organisms are being considered in assessments of reef health, bioacoustic techniques help to map and make explicit the relevant parties and the value judgements associated with them. This underlies the next steps too: acknowledging the possibility of alternative ways to approach reef health (which include different organisms or theoretical conceptions of health) and checking whether different value judgements result in such alternative characterisations.

3.2 Checking for sensitivity to values

The next step in Alexandrova's framework is to 'check if value presuppositions are invariant to disagreements' (Alexandrova, 2018, p.438). This means checking whether employing a specific theory or metrics of health, built around certain value judgements, produces a markedly different result to using those based around other value judgements. Checking this is important because it helps demonstrate how robust scientific conclusions are. If they do not vary when different values are considered, they are more robust, and adjudicating between value disagreements will be less important. If, however, different values result in different results, then more consideration is required about how to adjudicate and reconcile value judgements. That value judgements impact characterisations of changes to reefs is something I have demonstrated in the previous chapters, for example in the case of surprisingly positive assessments of the appearance of tropical reefs in previously non-tropical places, or disputes over the status of alternative reef states such as algae dominated reefs. Some work in bioacoustics checks for variation due to different value judgements

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[95] i.e. disvalued in a certain sense, typically related to the history and ecology of the species and its presence in the area (Helmreich, 2009, chap.4)

almost by default, by factoring auditory physiology of different reef organisms into assessments of changes to the reef, such as in the case of noise pollution.

3.2.1 Assessing noise pollution

Marine noise pollution, often defined broadly as anthropogenic sound with deleterious effects on marine life, has been steadily increasing in prevalence over recent history (Chahouri, Elouahmani and Ouchene, 2022; Slabbekoorn et al., 2020; Ferrier-Pages et al., 2021)[96]. Regulations for marine noise pollution have tended to be based around possible disturbances to nearby humans, and propagation of sound through the air to those humans, with comparatively little work done to understand and protect marine organisms, particularly fish and invertebrates (Jain-Schlaepfer est al., 2018).

As well as water having different acoustic properties to air, there are also many different mechanisms which can be used for detecting sound in water, for example, the use of hair-like sensors or membrane-like ones (Simpson et al., 2011). Marine organisms make use of a range of such mechanisms, some very different to human hearing. For many organisms, their entire body is moved with the sound wave in the water around them, and they instead detect the motion of particles in the water near them, rather than the overall wave itself. Humans, and some marine animals, have membrane-based sensors which detect sound pressure waves. Techniques can be designed to monitor sound in both of these forms:

Quote 100

> ‘We also use a kind of specially made recorder for a different, so underwater, there's two types of sound. Two components of sound, **there's sound pressure and particle motion. … particle motion is actually the more important component of sound underwater**, and in terrestrial environments sound pressure is the most important component, it's what we listen to, we hear sound pressure, most terrestrial animals will focus in on sound pressure, **but underwater, it's actually particle motion that is the acoustic component that fish and most invertebrates will be attuned to**. **So we use an accelerometer to pick up particle motion underwater**.’ 1004

As with visual and audio methods more broadly, the two types of sound here involve distinct measurement practices, but can be integrated to better tackle a

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[96] One implication being that an entire multispecies acoustic world has been lost or severely diminished, including the possible use of surface vibrations in the Earth by humans. For more on this see the chapters on sound and surface vibrations in Yong (2022).

problem: here, of understanding marine noise pollution. Measurement of noise pollution is traditionally done using microphones which work on broadly the same mechanisms as human ears, that is, they detect sound pressure waves (Nedelec et al., 2016). However, when devices like those described above are used, i.e. ones which incorporate the perspectives of other organisms, the results are not always the same. In some cases, noise pollution via particle motion may be audible to organisms where sound pressure is not, and vice versa, depending on things like the distance from the sound source, depth of water and the kind of organism listening (Nedelec et al., 2016; Montgomery and Radford, 2017). This means that past inferences about noise pollution, based solely on sound pressure measurements, have neglected to factor the impact of noise pollution on other organisms with different perspectives (Nedelec et al., 2016; Jain-Schlaepfer et al., 2018).

Depending on environmental factors and methods of measurement then, quite different understandings of the extent and impact of noise pollution can be produced. This nicely depicts the role for the perspectives and values of various organisms in this case: devices and metrics can be designed and employed because they are relevant to the forms of life scientists are interested in and care for. These techniques can be tweaked depending on which organisms are to be included. Bioacousticians are acutely aware that concepts such as noise pollution vary depending on the perspectives being considered, and recommend taking steps to ensure the right ones are considered for a given case.

They can, for example, calculate when sound levels would be detectable, disorienting, or physiologically damaging for fish, and can factor these thresholds into measurements of marine noise (Nedelec et al., 2016; Jain-Schlaepfer et al., 2018). This can be done via experimentation, for example in the case of the embryos of *Amblyglyphidodon curacao* (a reef fish), traditional noise pollution measurement techniques suggest that different kinds of boat engine (four- and two-stroke) have little difference in terms of their acoustic impact on fish embryos. But, using metrics more attuned to the way these embryos likely detect sound, and factoring in the hearing thresholds these embryos likely have, the difference between two-stroke and four-stroke engines becomes much greater: sound from two-stroke engines has a much greater volume from the perspective of these embryos. Not only this, but the impact they have on the physiology of the organism – in this case, the heartbeat of the embryo – is noticeably higher (Jain-Schlaepfer et al., 2018, p.7). So, once the physiology of a specific organism is factored in[97], different conceptions of noise pollution result. It is not enough to simply assume that human hearing in air is a good model for considering the impacts of noise on other organisms in water, unless these organisms are not valued sufficiently to be considered. (This is an example of the kind of ecologically motivated idealisation I return to in the next chapter.)

This demonstrates the kind of sensitivity to values which Alexandrova's second rule is aimed at, by checking if results differ depending on underlying values. In this case they do. By caring about the physiology of different organisms, the result is different theories, concepts, and practices. In this case, by including the mechanisms by which specific fish hear, and the thresholds associated with their hearing, different concepts of noise pollution, theories about its extent, and measurements of its impact can be developed. These will differ compared to cases which focus on impacts on humans, or on organisms which hear through different mechanisms[98].

Which of the many ways of detecting sound are worth including in measurements, itself related to the question of which organisms in the ecosystem are considered valuable, has a direct bearing on the concepts and practices associated with marine noise pollution, and give different results when measuring it. Knowing more about the nature and conditions of existence of an organism allows us to factor these differences into our assessments of their environments. Bioacoustic techniques, in focusing explicitly on 'characteris[ing] underwater sound in relation to the acoustic capability of particular species (acoustic habitat), and discover[ing] the role of acoustics in the lives of marine animals' (Montgomery and Radford, 2017; Clark et al., 2011), demonstrate an acutely perspectival mode of science, one which prioritises the study of the

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[97] Along with its life stage, as perceptual systems may vary with stages of development.

[98] And this is not the only example of such differences. Another involves the units of measurement available for quantifying particle motion in marine systems, i.e., noise pollution from the perspective of organisms which hear through this mechanism. Several units of measurement (and associated practices) are available. Those studying coral and fish recommend employing units of measurement which most closely fit with how the organism being studied would detect it (Nedelec et al., 2016).

lifeworlds of different organisms in the reef system, and of the impacts of various features of that system on the organism, i.e. helps to unpick the ways it is valuable for them. This not only allows scientists to check the impact of considering those organisms, but allows for a range of activities which amount to a kind of consultation of the relevant non-human parties, albeit via coral scientists. This is the final of Alexandrova's three rules for producing reliable and relevant results.

3.3 Consulting relevant parties

Finally, bioacoustics also allows coral scientists to apply Alexandrova's final recommendation to non-human organisms: 'consult the relevant parties' (Alexandrova, 2018, p.439). In cases where value judgements influence scientific processes, especially when different value judgements produce different theories, concepts, or data, it is important to include the full range of stakeholders. In human cases, methods such as deliberative polling – e.g. asking survey participants what they think about the survey questions – can be used to include the thoughts of those being surveyed beyond their response to answers (Alexandrova, 2018, p.349). Alexandrova suggests including scholars with different approaches to the phenomenon under examination, as well as the researchers actually measuring it, the users of the knowledge (e.g. policy makers) and the subjects who are likely to be impacted by it (Alexandrova, 2018, p.349). By providing opportunities for all of these groups to weigh in on the investigative process, scientists can capitalise on their expertise and knowledge (including normative knowledge) whilst avoiding drowning out other voices or becoming overly paternalistic, as has been noted in other cases (Wynne, 1995).

Other areas in philosophy of science have made similar arguments: standpoint and feminist theorists have stressed the need for diverse groups of actors to contribute to knowledge production if the theories produced are to be reliable (Harding, 1995; Longino, 1987). Advocates of updating science for a 'post-normal' age, that is, one where scientific issues often involve a variety of stakeholders and topics of high uncertainty and/or risk, advocate for tackling these issues by consulting extra-scientific groups through extended scientific processes (Ravetz and Funtowicz, 1999; Funtowicz and Ravetz, 1993). That is, they suggest deliberative and consultative processes by which other (human) stakeholders can be included in decision-making. These processes allow analysis and deliberation to be combined, drawing in groups from outside of science, through mechanisms such as juries and panels of stakeholders (Douglas, 2004a). On top of classical papers in sociology on scientists acting as spokespeople for non-humans (Callon, 1984), there have also been recent calls to extend post-normal scientific processes to non-humans (Connor and Kenter, 2019, p.1253).

By increasing opportunities for scientists and the public to influence one another, consultation can help include diverse human viewpoints in scientific processes (Douglas, 2004a, p.157). Douglas offers three ways public consultation can help inform scientific processes: i). framing the problems to be addressed; ii). providing key knowledge of the local conditions related to the problem and iii). providing insight into the values that shape the relevant analyses (Douglas, 2004a, p.158). I refer back to these three mechanisms of public consultation throughout this section to illustrate how including non-humans in scientific processes can provide benefits to the baselining process. Standard human-oriented methods will not be straightforwardly applicable: conversation and verbal deliberation are not an option. Bioacoustics offers some suggestions for how this can be done despite these constraints.

3.3.1 Understanding the stakeholders

Just as experts can help with decisions about value laden-concepts in human contexts, so consulting with non-human ‘experts’, i.e. those adapted to reef conditions, and learning to sense in similar ways to them, can help with developing the kind of evaluative knowledge required to reliably assess ecosystem health. The simplest way to include non-humans in consultative processes is to try and understand the interests of the organisms by recognising their existence and learning about the conditions under which they survive and flourish. In discussions of human well-being and health there have been similar claims made about understanding human nature and biology, and debates about whether this allows us to understand better what is good for humans (Glackin, 2016; Gorski, 2013; Nussbaum, 2001). Such claims can take very different strengths, including extreme (and very paternalistic) versions which argue that what is good for humans can be determined entirely by understanding their biology. Given the enormous plasticity of human nature, such approaches are both unpalatable and unworkable (Dupré, 2018). Humans engage in a wide range of practices which have a variety of normative significances, most of which will not be clearly reducible to narrow biological considerations such as fitness (Rouse, 2023a, chap.1). Similarly, even comparatively simple organisms can interact with the world in incredibly plastic ways, so many of the dangers of grounding normative assessment in biology persist (Rouse, 2023a). My claim here is much more modest however, namely that understanding the biology and ecology of the organisms present in a reef system can help us better understand what is good for them, i.e. can amount to a kind of consultation, but that this is far from infallible or exhaustive, and offers further ground for exploration and consideration of non-human organisms.

As I argued in 3.1, integrating different methodologies, particularly ones which are widely used in marine environments and suit their constraints – such as acoustic methods - gives better insights into which organisms are present in a reef. In 3.2 I also showed that doing this can help us understand what those organisms are like, the ways in which their environments are significant for them, and how that may differ from our own experiences. Understanding this helps with framing investigations into problems on the reef, and better understanding the local conditions, as well as providing a platform for quasi-deliberative processes to take place, i.e. can help provide the benefits of public consultation put forward by Douglas, but in a multispecies context.

By better understanding the significance of the reef system for reef organisms, we can discern the conditions under which they can survive and flourish, and those in which they cannot. Much of the life sciences does this in various ways, looking at how different stimuli impact specific organisms. But a particularly promising avenue for this in bioacoustics is through the longer scale passive monitoring of environments. This allows more dynamic assessments of reef health which better take account of some of the kinds of variation discussed in chapters one and two, namely variation associated with changes in time, such as seasonal and daily variation, as compared to snapshot methods, where, for example, the composition of the reef is measured once, at a specific time. This kind of continual and passive monitoring was discussed by the following participant:

Quote 101

> "Yeah, I guess our, our broad hypotheses basically, is that you can learn additional things about the state of a reef and how it works from listening to it than you can from just looking at it. And it allows you to access reefs for longer than you ever can on a visual transect because … hydrophones can listen for … months at a time, whereas a visual transect is a single snapshot in time. And it allows us to measure at times of day that we usually can't get a window on, so we can do stuff at night as well as in the day. And I think it allows us to, to get into the heads of the animals that live on the reef in a way that perhaps visual stuff doesn't. So you know… a lot of them are acoustic specialists, they can hear really well, they use a range of noises. And so by only sort of studying what we can see of a reef, we maybe missed some of the interactions and the underlying ecology going on." 1003

Quote 102

> "[sound] could give you … maybe a better understanding of the total biodiversity, **but also how that changes during the day and during the seasons**. Because when you put that recorder down … you can take samples and then you can have up to a year, or you do continuous recordings and then you can get up to four months in these kind of environments. So you get a much more complete overview of what is going on. And in theory … you could just get the data out, put some new batteries in and put it back down. **So you could then track over the long term, how biodiversity is changing, how maybe marine protected areas are recovering**. …
>
> So sound hopefully will help us to monitor those reefs more closely, and track their health and track their status, and just understand how they're working. Because still we don't really know … how the seasonal patterns might affect these deeper ecosystems." 1024

The relevant points made here are that bioacoustics lends itself to the production of systems by which reefs can be monitored continuously or over longer times, and that this gives a better insight into the underlying ecology of the system. This allows for changes associated with specific events to be examined, building up a better picture of many reef organisms and the overall ecosystem. This is especially important given the strong influence timescale has over baseline construction. Changes within the ecosystem might be innocuous, like night and day cycles, or less so, like changes in noise associated with changes in boat traffic due to a global pandemic[99]. Either way, this allows for a rudimentary form of consultation ('getting into their heads'), based on repeatedly and continuously examining organisms over longer periods of time. It is, in this sense, more deliberative, allowing the significance of changes to reef environments to be better examined, rather than simply examined in one-off snapshots. This enables a deeper understanding of how the environment

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[99] For an example of this, see Clippele and Risch (2021)

supports specific organisms and the impacts changes to it have on them, and so better enables the perspectives of those organisms to be considered and factored into baselines. In Douglas' terms, it provides a more comprehensive insight into the local conditions being examined, both in terms of the richness of the examination, but also in terms of the timescales, and also provides an insight into the significance of the environment for the relevant organisms, i.e. gives us a sense of how it is valuable for them.

3.3.2 Integrating communities and articulating phenomena

As well as enabling more detailed study of the organisms in question, these techniques also enable us to integrate coral reef organisms into our epistemic communities more effectively. Epistemic communities are groups of people bound together by practices, arrangements and mechanisms of knowledge production in a given area of expertise (Knorr-Cetina, 2013, p.363). They are simultaneously social, economic and political communities, the production of knowledge being shaped by and also shaping society (Knorr-Cetina, 2013). Incorporating diverse communities into scientific processes, and bringing them together to tackle a shared problem or understand a phenomenon across contexts can often be fruitful, as many pluralist philosophers of science have argued (Harding, 1995; Brigandt, 2010; Longino, 1987; Massimi, 2022; Giere, 2006). I would add to this that epistemic communities do not stop at the social, but include socio-ecological groups, and that consultation and integration of a range of non-human epistemic organisms can provide benefits too[100,101].

By bringing together methodologies and data which recognise and recapitulate the perspectives of reef organisms, bioacoustics allows for a stronger epistemic connection between human communities and non-human ones. This process is

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[100] Clearly, non-humans cannot be included in epistemic communities in exactly the same way as humans – they are not knowing contributors to knowledge production, nor the full and equal partners envisaged in philosophical debates about the marriage of epistemic communities (Van Fraassen, 2005) – but their perspectives can be partially included in a way which renders phenomena relevant to them also relevant to humans. Whilst discussion of epistemic communities often does not involve non-human organisms (e.g. Massimi (2022, p.258); Knorr-Cetina (2013)), there is no reason why the ability of other organisms to recognise and track patterns cannot be included, such as, in this case, the ability of fish and coral to detect good quality or healthy reef habitats.

[101] Following Brigandt (2010), I do not expect integration of two things to imply permanent or complete union, but merely that they can be brought together in a particular situation to address a matter of concern.

still in its very early stages, as articulated in interviews, including in the quotes I first used to introduce bioacoustics at the start of the thesis (Quotes Quote 4Quote 6), and in the discussion about seasonality in Quote 102:

Quote 103

> “a healthy reef sounds like there's a hell of a lot going on, lots of little pops and whistles and grunts, and, you know, chattering and snapping, and **some of which we understand what animal's doing and why it's making that noise, and some of which we've not got a clue**.” 1003

Quote 104

> “And with sound, the idea is that even though we don't have a full library yet of all the sounds that the fish would make in an area, it could give you an idea of all the different sounds and maybe a better understanding of the total biodiversity” 1024

In order to use these sounds to consult the resident organisms and get a better sense of the local conditions and the values which can shape analyses of reef health, scientists need to be able to understand the significance of the sounds they are detecting, both for us as human observers, and for the various local residents. Whilst the significance of broader soundscapes has been made clearer, e.g. by showing that certain features (e.g. certain proxies of complexity) correlate with healthier or more attractive reefs, including from the perspectives of specific organisms, many of the smaller scale features are still obscured (‘we’ve not got a clue’, ‘we don’t have a full library yet’). But by continuing to explore these sounds, and observe and experiment with them in the ways outlined above, bringing them into dialogue with existing techniques which are already well theorised and articulated, we can better understand the significance of unknown sounds:

Quote 105

> ‘I think generally … these acoustic indices … we haven't been able to fine tune them yet. So usually, when we're making our comparisons, it's noticeable that that reef is a healthy reef versus a degraded reef, like, we'll basically be putting a recorder near a place that's got coral, it's got fish.. [and a] place where it's mostly rubble. So obviously, you're going to have these big differences between them. But what we're trying to now work on is… can we stick a recorder in a reef that basically looks like any other reef and then use that recording to tell the health of the reef versus another reef? And I think it's very much in the baby processes of it. So I'm not sure if I'm answering the question, but I think it's going to take a lot of kind of integrative methods where you need to have those standard measures for healthy reefs. So you need to also integrate fish surveys, coral covers, like all those major components that you use to identify the health of a reef, plus the recording, and then compare that to another reef where maybe it's a step down in health and you can get that from the coral

> cover, and the number of fish. But to the eye test, it looks like a coral reef that's the same. And then look at the recording and see what the differences are. But right now we don't have that capability. It's something that the group is actively working on, other groups are actively working on it. And there's been some headway in it again, with kind of those functional routes I was talking about. But it's very much not there yet.' 1004

So the presence of some well-studied organisms can be inferred from sound, relative to somewhere lacking these organisms ("a place that's got coral, it's got fish … [and a] place where it's mostly rubble"). But when it comes to more complex judgements, for example those which are intermediate ('a step down in health') or which are not amenable to visual analysis ("but to the eye test, it looks like a coral reef that's the same"), integrative methods are required to better grasp the significance of these acoustic signals, both for the organisms resident there and for human investigators.

This process of understanding and making amenable to discussion, investigation and manipulation is what Joseph Rouse has called 'articulating' phenomena, that is, designing systems which allow us to make previously inaccessible or obscure phenomena accessible to us, and enabling communication and reasoning about these phenomena (Rouse, 2014). Articulating a phenomenon allows us to think about, recognise, discuss and act upon it, where previously we were not able to (Rouse, 2014). In this case, scientists articulate phenomena which were previously already accessible to other organisms. The process of articulation here involves looking for relations between known cues about reef health ('fish surveys, coral covers… major components that you use to identify reef health') with the recordings of sounds which are less well understood.

The experiments and observations I have discussed throughout this chapter help to do this. By combining different scientific techniques and practices, it becomes possible to further tease apart the meaning of different features of the marine soundscape. Normally human ears aren't suited to this, given that they are adapted to terrestrial sound. Production of instruments, specifically hydrophones (underwater microphones), allows for detection of underwater sound, and may be tailored to certain versions of transmission and detection. Other instrumentation, such as choice chambers, allow for a deeper understanding of the significance of this sound to be gained, including by showing that coral or fish are attracted to, repelled by, or stressed by certain sounds. Motorboats, speakers and other devices allow for further interventions to unpick and articulate the key features of the acoustic world of these reef organisms, by providing different audio stimuli and looking at the impacts of this (Jain-Schlaepfer et al., 2018). These techniques provide us a window into worlds which are normally hidden from us, helping us to access features of the ecosystem which are relevant to the lifeforms there. They amount to a material transformation of the environment of the scientist in order to make the auditory world of reef organisms accessible and comprehensible (Rouse, 2014)[102].

They also help us to articulate those features in ways which make sense to us, and which make phenomena tractable, notably by combining these techniques with pre-existing ones, such as visual surveys and censuses. Bioacousticians may start to develop a feel for the kinds of sounds produced by different organisms, and a vocabulary begins to emerge to describe types of sounds: grunts, whoops, pops, whistles, fishsong, evening and morning choruses[103]. Each of these can – at least in theory - be associated with specific organisms or phenomena, and used to better understand (and, in some cases, intervene on) the reef system. Efforts are now underway to produce databases of biological marine sounds as well as a system for standardising names for different sounds, which will allow for further scientific articulation of the acoustic worlds of these organisms (Parsons et al., 2022; FishSounds.net, 2023; Rountree, 2023). Similarly, machine learning can be used to extract information from a soundscape, such as how healthy a reef is (according to some pre-determined background theory of health) and what species are present (Williams et al., 2022). Citizen science is expanding into this area too: interested non-scientists can now contribute to a richer understanding of marine environments through Google's 'Calling in Our Corals' experiment, where participants learn to identify reef sounds and then pick them out on marine recordings for the benefit of machine learning systems (Google Arts and Culture, 2023). Reef bioacoustics amounts to an emerging jointly material and conceptual system which allows for

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[102] A similar story could be told here about scuba diving and how that has made aspects of reef accessible to scientists for the kind of visual surveys often conducted today (along with many other practices). This forms part of a larger story about the interweaving of human and coral niches – part of the ecology of coral science – in a way which shaped the development of scientific practices. I return to this in the final chapter and thesis conclusion.

[103] For a captivating example of this kind of vocabulary, see 'Changing the soundtrack of the Ocean | Steve Simpson | TEDxExeter' (Simpson, 2019)

the unpicking and articulation of patterns in nature which are relevant to other organisms and previously were inaccessible to us (Rouse, 2016b).

In doing so, we bring not only different human epistemic communities together, but also human and non-human ones. Scientists are producing a ‘merged realm of existence’, where non-human objects are brought into human epistemic processes (Knorr-Cetina, 2013, p.365). Importantly in this case, these objects themselves have perceptual systems, and these are used to reconfigure the way coral scientists interact with the environment. Instead of simply capitalising on the constraints and affordances of human-environment interactions, they also capitalise on those of non-humans and their environments (Knorr-Cetina, 2013, p.366).

Coral reef bioacoustics thereby offers a chance to combine what Ernest Sosa calls animal and reflective knowledge. Animal knowledge, in Sosa’s terms, is knowledge which the knower has no beliefs about the reliability of. Reflective knowledge is knowledge which we have beliefs about the reliability of (Sosa, 2001, p.193). Whilst he is talking primarily of human cases, here we can take strategies which have worked effectively for other organisms – which may be considered to constitute (presumably) unreflective animal knowledge of the nature of their environment, i.e. a kind of evolutionary wisdom – and use them to inform our understanding of the nature of the environment. But we are also able to reflect upon the knowledge generated from such techniques, for example by combining them with existing techniques, and assessing their reliability over time, as well as reflecting upon their origin, development and success in other organisms (for example by experimenting with the processes that lead to fish swimming towards certain sounds and not others (Simpson et al., 2010)). This combination of tried-and-tested systems for understanding the environment, and reflective analysis of such systems, provides a way of strengthening inferences drawn about conditions on reefs, even before combining bioacoustic techniques with other non-acoustic ones. The objects of scientific knowledge (fish and coral) thereby shape the perspectives of the subjects of scientific knowledge (coral scientists) in ways which bring their lifeworlds into a greater degree of overlap (something others have argued happens throughout science generally (Knorr-Cetina, 2013)).

Integration of epistemic communities, operating through a range of methods - visual and audio, observational and experimental, passive and active - allows for the significance of changes to reef environments to be better understood in a way which includes reef organisms:

Quote 106

> “I mean it's connecting us in a new way with the reef, in, like you say, both for the management, but also just from the pure, ethereal animal connection that we have with nature” 1002

This has resonances too with the quote from the beginning of this chapter:

Quote 107

> ‘And so learning how other animals sense their environment helps us get inside their heads rather than look down on them. And that's where I think the most exciting discoveries are… one of the phrases we coined with coral reef restoration was learning how to think like a fish. … that's the better way than to think like the fish biologist’ 1002

As alluded to here, the set of material transformations of the environment (hydrophones, choice chambers, motorboats) and associated practices allows for resident organisms on a reef to be better consulted in the formation of theories and concepts related to reef health. This new pluralistic form of sound becomes a stronger shared connection between humans, reef organisms, and the reef, capitalising on an ‘ethereal animal connection’ with nature. Future interactions with the ecosystem can take account of how changes will be perceived by these organisms and how they might respond. This allows for a reduction in the anthropocentrism of the theories developed, and helps ensure that concepts such as ecosystem health reflect the perspectives of valued organisms – helping us to ‘think like a fish’ – and enable the integration of non-human lifeworlds into human scientific processes.

The interview participant is, of course, not talking about literally thinking in exactly the same way as a fish. But what is happening is that the relationships between reef organisms and their environment – and between them and our environment – are being unpicked and examined in ways which allow for the things of value to them to be built into our scientific theories. In Douglas’s terms, this amounts to consultation because it enables these organisms to influence scientific understanding of the local conditions under which they exist, and the understanding of the values which are relevant to the scientific process here. In particular, when scientific study is focused on concepts like ecosystem health, it helps to have a diverse range of perspectives to include, to ensure that the concept being employed is one which is socio-ecologically objective in a procedural sense, i.e., isn’t dependent on a narrow range of values derived from one species or perspective on the ecosystem. For example, before noting that sound pollution may travel different distances when measured with different sensory systems, our concept of reef health would not line up well with concepts based on the needs of lifeforms which hear through such sensory systems. Likewise, reefs which appear healthy – for example having high coral cover – may turn out to be lacking specific cryptofauna which can otherwise not be detected. Using bioacoustics allows us to check our assumptions, compare different versions of reef health, and incorporate the interests of non-human organisms into our assessments. In doing so, it allows for consultation of the organisms, providing insight into the ways these systems are valuable for them, allowing for socio-ecological oversight over the production of scientific characterisations of these ecosystems, i.e. the kind of procedural objectivity Alexandrova’s rules are designed to produce, but expanded to include ecological and non-human concerns. Better inclusion of non-humans in our knowledge generation processes thereby allows for better inclusion in social, economic, political and ecological theorising and decision making, and a kind of feedback between knowledge generation, care, and stewardship (Helmreich, 2009, p.240).

4. Multispecies baselines in and beyond science

When a fish or coral swims towards an attractive reef, or a specific sound – bearing in mind the possibility of mistakes – this provides clues as to the meaning of that stimulus, and the associated ecosystem state, for that organism. To expand on a quote from earlier:

Quote 108

> ‘… they can discriminate somehow, the different types of sounds, so that they are attracted by high quality habitat, but not by poor quality habitat. So they obviously don't have a memory of all those different habitats, types of habitat, they don't even have a brain, but somehow that they're wired to move in different ways when they're stimulated by different types of sound. And a healthy coral reef is a noisy, vibrant, diverse soundscape. Because it's the noise

> made by all the animals. And the corals, both swim towards it and swim downwards when they hear that sound or experience that sound.’ 1002

Here, by studying the significance of certain phenomenon, say, for instance, a given soundscape, for a reef fish, we are given a glimpse into what this phenomenon means to the organism. In this case, they combine several methods of assessing the health of a reef ecosystem – various traditional human measures, and different acoustic sensors which are relevant to marine organisms – and use these different perspectives to tell us about an overlapping set of phenomena, namely the health of the reef relative to humans and other reef organisms (who often share in benefitting from the same ecosystem arrangements). Here then, the target phenomenon is one shared by humans and non-humans, i.e. the attractiveness and suitability of the reef habitat. This allows for assessments of the reef which have had oversight, of sorts, from a range of socio-ecological entities. In doing so, it allows for multiple species to be incorporated into the value-laden aspects of the baselining process. By incorporating variation in niches, perceptual systems, and physiology of different organisms into the scientific process, this extends typical concerns about procedural objectivity, reliability and extended peer review in a multispecies and more ecological direction. I explore these socio-ecological dimensions of science more in the next chapter.

Finally, it is worth noting that this process can extend beyond science. By allowing socio-ecological oversight, bioacoustic techniques can allow human decision-making outside of science to be informed by ecological considerations and the perspectives of non-human organisms. The following interesting example was raised in discussion during one interview:

Quote 109

> ‘In terms of who pays for restoring reefs. One of the most powerful ways of doing this is through insurance, bizarrely. But that's because hotels, local villages, pay huge premiums against environmental damage from storm surges, from big storms, from sea level rise even. But coral reefs naturally provide a real buffer against the elements. And if you've lost your reef, you've lost your protection. So if you can rebuild your reef, you can pay less on your premium for your hotel. So now, the United Nations Environment Program have coined the phrase that you can try to save coral reefs one insurance policy at a time. Where through demonstrating your reef recovery, then there is there is financial value in restoring the habitat. But to do that, your astute financiers want to know whether it's actually working. And we're finding that acoustic monitoring is one of the most unequivocal objective ways of measuring the health of your reef … if I worked for an insurance company, and I paid you to go and count fish on the

> reef, and then the next team were paid by the hotel, they might not always count the same number of fish if there are benefits and costs to what the answer is. But the acoustics are uncheatable. So it provides that extra safety net in terms of the objectivity of the measure.’ 1002

Here, the argument is that bioacoustics can be used to provide a reliable set of indicators to bolster programmes to save reefs outside of scientific contexts, in this case providing evidence about the vulnerability of property to coastal flooding. Techniques like machine learning can also be used to increase the scale and scope of these activities, for example by training algorithms to identify degraded and healthy reefs from sound recordings (Williams et al., 2022). Through means such as these, phenomena such as reef health and noise pollution – examined with consideration of the perspective of a fish or coral – are made even more accessible to other areas of society. This allows, for example, insurance companies to link premiums to the health of local reefs, as healthier reefs provide greater protection from flooding.

This is a case of involving diverse socio-ecological stakeholders in processes designed to deal with high uncertainty and high stakes problems, i.e. is a multispecies form of post-normal science (Ravetz and Funtowicz, 1999; Connor and Kenter, 2019). When facts are uncertain or contentious, values in dispute, stakes are high and decisions urgent, post-normal science advocates suggest consulting the extended peer community which is impacted by changes to the system being studied. Consulting this community allows for under-appreciated sources of knowledge to be incorporated into decision making, and can help make assumptions and values more explicit, thereby allowing the interests of multiple groups to be considered and acted on (Funtowicz and Ravetz, 2008). Processes like *extended peer review*, and *production of extended facts*, involve extending normal scientific processes outside of the traditionally conceived scientific community, inviting others to help assess evidence and theories, and thereby designing systems to respond to high-stakes threats and uncertainty (Ravetz and Funtowicz, 1999).

Typically, post-normal science advocates consider only human stakeholders, but this need not be the case. As I have argued here, bioacoustics offers an opportunity to, in a sense, consult non-human organisms, by helping provide information about what is valuable for them, and about what is valuable for us. As such, coral bioacoustics can help produce multispecies post-normal scientific procedures, and thereby help meet the challenges of the high-uncertainty high-stakes coral reef crisis. Incorporating scientific perspectives relevant to the lives of important non-human organisms into financial decision-making outside of science offers a way of economically tying together human and non-human stakeholders and of helping to mitigate the high-stakes high-uncertainty situation reefs and their associated organisms (humans included) face. Here, insurance companies have the ears of coral and fish, and both they and local residents benefit from the robustness and relevance of concepts of reef health which include the perspectives and capabilities of multiple types of organism, i.e., concepts which have socio-ecological objectivity, in the procedural sense.

5. Care in coral science

It is also worth noting that, as with many other areas of animal research, coral bioacoustics has a strong affective and ethical dimension. The process of producing knowledge about how reef organisms perceive and value their environment involves the intertwining of ethics and welfare as a constitutive part of the science, as has been noted in other animal research (Friese, 2013; Davies et al., 2018). Whilst I have primarily discussed here the benefits of such techniques in terms of better understanding how environments are valued, and producing robust and relevant assessments of environments, these practices also amount to a kind of care for both reef organisms and the ecosystems they are parts of. Coral science work here involves not just the instrumentalisation of animals, but ethically-charged encounters and cultivation of shared interests and responsibility (Davies et al., 2018; Haraway, 2009). This mixture of more-than-instrumental concerns for reef organisms showed up too in the last chapter, and is a key part of understanding the socio-ecological dimensions of coral science, explored in the next.

By bringing reef organisms into the lab, or bringing the lab to the organisms, (e.g. through choice chamber or motorboat experiments near the reef) scientists produce systems for translating insights about these organisms into insights about the broader ecosystem, and for the place of those organisms in those ecosystems. The translational structure of other kinds of animal research – such as in medical science – is preserved here, but with a key difference: the aim is to better understand the animals and the ecosystems they are parts of, in large part for the sake of protecting them, rather than for more directly human concerns (Friese, 2013). This concern for other organisms, both those directly being studied and those in the broader environment, is common in biology (Haraway, 2009). Whereas in medical settings animals often serve as proxies for human biology, here they serve as proxies for other members of their own species, closely related species, and the broader ecosystem, i.e. for a range of non-human interests as well as human ones (this is discussed more in the next chapter of the thesis). There is a strong affective dimension to such studies. Similar to findings from studies on instances of experimentation on mice in labs (Friese, 2019; Davies, 2013), here coral science practitioners care strongly for their study organisms. This care is not some extra-scientific phenomenon, or something which negatively distorts reef research, but something which runs through all of it, enhancing both the relevance and robustness of the research (Friese, 2019). Researchers make decisions which reduce the distress felt by study organisms, where possible:

Quote 110

> “we often bring fish into the lab, and work with simplified arenas and simplified environments. And for that we use clownfish a lot. They are very easy to breed in captivity, they're naturally fairly sight attached, so that they don't get freaked out by being in a fairly small tank, because that is their natural environment to be in a small space. …
>
> whereas if you had say, a roaming parrot fish that was in a tank, it would feel very constrained.” 1002

Here the epistemic and the affective are intertwined: distressed fish are, broadly speaking, not representative of their relatives in the wild, so it helps to study fish which are not ‘freaked out’ by the study environment. This kind of conclusion has been drawn in other areas where animals are brought into labs (Friese, 2019; Davies et al., 2018; Haraway, 2009). There are also some interesting differences here, though. Notably, bioacousticians also use field experiments commonly:

Quote 111

> “And then we also work in mesocosms on the reef, or we'll build small areas of reef on the sand flats, then we have discrete experimental units that we can work with. But we can manipulate them in a much more controlled way, compared to just simply observational studies on natural reefs. …

> And you know, there's several reasons to do that, one of which is things like water chemistry, and tides, and illumination and things that are quite hard to replicate in the lab. But also sound in the lab is very different to what you can ever do in the wild, because it bounces off the sides of your tank. So you end up just with this echo chamber with stuff going on. Whereas in the wild, you're in what's called boundary free conditions where the sound will travel away from the source, and you can work in a more natural acoustic environment, and then you can also actually use real sounds. So you can put your arena near to a coral reef or you can drive motorboats around your experiment.” 1002

Here, the field work allows for both better epistemic conditions for picking apart the significance of phenomena for non-human organisms, but also can help reduce the restraints that organism distress puts on research (which may be considerable, with animal stress well-recognised as impeding the value of scientific results (Davies et al., 2018; Friese, 2013)). The translatability point also surfaces here again: these conditions are more relevant to the systems which scientists care about, which are, in this case, the reefs themselves and the organisms which live in them. Studying these in the lab is difficult because of the various constraints (acoustic properties, water chemistry, tides, lighting etc.) and so if the reef is to be understood it helps to conduct studies in conditions relevant to it. Concerns about the health of reef organisms also extend to other kinds of reef study, including movements away from the use of dredging to capture and study materials and organisms from reefs:

Quote 112

> “[on studying deep sea reefs] But more usual is to use... Well, the easiest and cheapest is to use a dredge, you basically just lower down a piece of metal on the rope and scrape along the sea floor and see what you can get. Now, people have been using that method since 1869. **But I've been on trips where they do that around Italy, for example. And the scientists on board quickly realized that we'd actually damage, quite highly damage, what they're trying to study, if they carried on doing it that way**. And so the normal method these days probably is to use a remote operated vehicle, which sends its images back up a cable to the wheelhouse on the ship.” 1016

Even though these methods are cheaper, then, it does not make sense to use them, because they damage the things scientists are trying to study. The speaker did not make it clear whether the concern here was epistemic or affective, but given the tone of discussion around trawling throughout the rest of the interview, it is fair to assume there is an affective dimension. The overall point here is that how research takes place matters. By getting to grips with reef organisms in less harmful and less destructive ways, it becomes possible to develop greater intimacy with and understanding of other lifeforms, and thereby to gain insight into how the world is valuable for them, and refine how we value ours, without succumbing to the trap of socio-biology. Instead, we have here a kind of naturecultural approach, i.e. one where values are not simply read off of nature but more painstakingly and partially derived from intimate study of it (Rouse, 2023*a*, chap.1; Haraway, 2003). It is no coincidence that care and epistemic concerns line up here. The aims of coral science are a complex mixture of epistemic and non-epistemic concerns which centre around the flourishing of a range of organisms, and so relate strongly to both epistemic and affective relations with the objects of coral science study, something I explore further in the next chapter.

These affective connections run through all of the work discussed here. Coral scientists are, in part, driven by care for the broader reef environment and the organisms within it. They aim to study and understand these organisms better by using bioacoustics techniques so both the study organisms and their associated ecosystems can be cared for. Interactions between humans and reef organisms enable the performance of practices which have epistemic benefits but also help us to see these organisms as subjects and partners (Haraway, 2016, chap.1). By doing experiments outside of the lab, or by selecting organisms which are less distressed by laboratory conditions, they can maximise the relevance of their work, and minimise the suffering and distress of both the organisms involved and the organisms they represent. They develop techniques which allow these organisms to be consulted and their values included in scientific assessments (and broader societal decision-making), enabling them (and others) to better care for these organisms. These practices are, in a sense, an extension of the work done in laboratories whereby researchers develop intimate knowledge of their objects of study and learn to tell whether they are flourishing or not (Friese, 2019). Bioacoustic methods also allow for variation within species to be captured, so for individual organisms to be recognised *as individuals*, that is, as subject to 'true historical particulars', i.e. not simply replaceable like for like with other organisms of the same (or different) species[104] (Friese, 2019; Harding et al., 2019). The uniqueness of

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[104] One particular passage from an article by a bioacoustics practitioner articulates this strongly, so I include the entire quote here: "Wherever humans are causing changes to the environment—and we are doing so at an unprecedented rate with respect to, for instance,

organism behaviour has been recognised as a way of individuating organisms (Trappes, 2022b) and also often develops as part of the kind of intimate and caring animal-human relations discussed here (Friese, 2019). As I showed in the previous chapter, irreplaceability is a key consideration in the ways coral scientists relate to their objects of study.

In Haraway's terms 'multispecies flourishing requires a robust nonanthropomorphic sensibility that is accountable to irreducible differences' (Haraway, 2009, p.131), and here, because of their concern for the flourishing of reef species, bioacousticians look directly for the ways other organisms sense their worlds, explore how this differs from our experiences, and build this into theories, which thereby try to factor in such differences. Their interests are better discerned and responded to, and we are given the chance to - in the words of the participant in Quotes Quote 106 and Quote 107 - better connect with these organisms and 'get inside their heads'. Coral bioacoustics allows us to not only try to 'listen to the animals' then (Friese, 2019), but to try to listen *as* the animals, to consider our shared environment from a shared perspective, and to try to extend our ability to care for reef systems, their inhabitants and their dependents. The key point here is not that these methods allow non-human values to simply be reduced to biology or read off nature (as with ill-fated attempts at sociobiology in the past (Rouse, 2023a, chap.1)) but that they allow for non-human organisms to be factored in to human activities as both social and ecological entities[105], lifeforms and forms of life, and for scientists to establish stronger affective and epistemic relations with them in the process. It is not simply understanding the biology of reef organisms that matters then, but

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climate change, habitat destruction, chemical and light pollution—the same need for basic research combined with management plans is required; and the same importance should be afforded to the consideration of intraspecific variation. It is intuitive that different species may respond in different ways to any particular challenge; it ought to be equally intuitive that different individuals of the same species may be similarly different in their responses. When it comes to monitoring and managing threats to our wild ecosystems, we must be mindful of the Orwellian trope: "some animals are more equal than others." Both between and within species, variation is vital; now is the time for that understanding to take center stage as we attempt to maximize the mitigation of our activities."   (Radford et al., 2019, p.1517)

[105] This is to say that the organisms are considered as not just simply devices for maximising scientific understanding (analytic organisms) but as living beings (naturalistic organisms) (Lynch, 1989 via Friese, 2013, p.134). Scientific practice can benefit from embracing both of these guises simultaneously, treating animals as 'having a face' (Haraway, 2009), and as 'naturecultural' entities with life histories entangled with our own and embedded in systems of jointly social and ecological significance which have normative import for them as well as us (Rouse, 2023a). In short, as lifeforms with forms of life deeply wedded to our own.

undertaking investigations into this in ways which allow room for affect and care, and which are sensitive to the ways environments matter for non-humans.

6. Implications and conclusion

I have shown here that bioacoustic techniques of the type employed in coral reef bioacoustics can help in situations where values are an important part of understanding and responding to changes to coral reef systems. To understand the health of a reef system, and construct baselines to assess this, different socio-ecological actors must be considered. Ecosystem health and related concepts such as pollution are meaningful only relative to specific organisms, and groups of organisms, and so the existence, nature and perspectives of these organisms must be factored into scientific processes producing these concepts. Alexandrova's rules for doing this in human and social contexts can be extended to multispecies and socio-ecological ones, providing the kind of oversight and input necessary to ensure scientific procedures in socio-ecological contexts produce reliable and relevant results. This is not to say that bioacoustic techniques do this infallibly or comprehensively, but just that in cases where the aim is to understand and intervene on a multispecies system, factoring in the perspectives of other species into the scientific process will provide benefits when those species are themselves valued by humans. The more narrowly human elements of this story – which I have not covered here - are also still very important, including the well-established influences of things like social position on the production of knowledge covered by feminist epistemologists and standpoint theorists. Clearly, the methods used here are not a replacement for, but a complement to, the kind of deliberation, consultation and diversity which others have convincingly demonstrated is important for good scientific practice.

This chapter offers a case study for the challenge raised by Sharon Ghamari-Tabrizi and Donna Haraway, namely, to articulate how specific experimental practices are done and justified in the context of care for non-human organisms, and how this can subsequently shape science (Davies et al., 2018; Haraway, 2009). The interactions described here contribute to a picture of science not as a cold and indifferent exercise but one which aims to be attuned to the values, interests and lifeworlds of other organisms in order to better care for them, both within scientific contexts and in the broader environment[106]. I have aimed to show here that these attempts to understand environments in a way relevant to other lifeforms provide yet another example of how care for organisms and environments improves, rather than impedes, scientific processes (Haraway, 2009; Friese, 2019). In the next chapter I argue that this kind of care is constitutive of coral science.

By integrating perceptual systems of other organisms into our scientific processes, and thereby integrating these organisms into our epistemic communities, it becomes possible to evaluate socio-ecological systems with them in mind, and thereby produce baselines which avoid the narrow anthropocentrism driving many of the crises currently faced by humans[107]. This helps with the problem outlined in the first chapters of this thesis, ensuring that reasonable baselines are employed when assessing reef health. Bioacoustics demonstrates that non-human values need not be intangible or ignored, and in fact can influence scientific processes in beneficial ways. Care for other lifeforms, and attention to the ways the world is valuable for them, can be beneficial to the practice of science, producing more robust and relevant theories. By doing so, organisms are used both instrumentally but also treated as bearers of value for their own sake, i.e. more-than-instrumentally, not simply as parts of human environments but as entities with their own environments which can be modified to help them persist through the challenges faced by reef ecosystems. This offers a further example of how coral scientists refuse and navigate the oft-invoked dichotomy of instrumentalisation versus value-for-its-own-sake raised in the previous chapter (and articulated in Haraway, (2009)).

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[106] They also go towards fulfilling Hammer's Maxim: when you measure, include the measurer (Hammer, 2021)

[107] The arguments I have made here also relate to attempts by philosophers of biology to offer an account of illness as a partly socially constructed concept, but in the case of non-human organisms. One suggestion is to factor them in as members of an expanded conception of society which includes non-humans (Conley and Glackin, 2021, p.14). This is what I have suggested bioacoustics can do for judgements of the value of ecosystems from non-human perspectives.

Chapter 5 - Coral Reefs and the Ecological Dimensions of Science

Abstract

In this chapter I bring together the work in the previous chapters in order to explore the ecological dimensions of coral science, by which I mean how it shapes and is shaped by the living world around it, and the role of the different forms of value I have explored so far in this. This investigation parallels and complements exploration done by others on the social dimensions of science, i.e. the way society influences science and vice versa. Using ideas from niche construction theory, I offer more ecologically-grounded answers to traditional questions in philosophy of science: what is coral science? what is good coral science? and what roles do different forms of value play in coral science? In doing so, I examine which living systems are thought to and intended to benefit from coral science as an activity. The overall picture I present is one in which coral science is an activity primarily aimed at sustaining a diverse set of living systems, their interactions, and their ways of life, one which is responsive to the socio-ecological context it is embedded in, and in which different value relations between organisms and environments take priority depending on this context. This explains shifts in the practices of coral scientists (towards interventionism, and adopting medical repertoires) and criticisms of some of the practices engaged in by coral scientists. It also brings values as understood in philosophy into direct connection with the ecological value concepts discussed in this thesis: intrinsic and instrumental value, ecosystem services and functions, and relational value. The implications of this more generally are that science is influenced by and influences both social and ecological contexts, and so entangled with a greater number of social and ecological process than is typically considered. These should be considered when evaluating scientific practices, seeking to understand processes within science (e.g. baselining), or trying to understand changes to science (such as scientific responses to climate change).

1. Introduction

> ‘The whole of science is nothing more than a refinement of every day thinking.’
> – Albert Einstein (1936, p.349)
>
> ‘Scientists try to eliminate their false theories, they try to let them die in their stead. The believer—whether animal or man—perishes with his false beliefs.’
> Karl Popper (1968, p.347)

Under a glass dome in Arizona lies an unlikely ecosystem: a coral reef, built and shaped by humans in the ruins of *Biosphere 2,* a forebodingly ill-fated attempt to design a sealed ecosystem for humans to live in (Alling and Nelson, 1993). It now serves as a living laboratory, with one part – the largest ever controlled oceanic environment - used by marine scientists to study the fate of the world’s most famous dying ecosystem (Biosphere2.org, 2023)[108].

In February 1969, four marine scientists, aquatically-inclined but fundamentally terrestrial animals, dove down into a 30-square-metre chamber below the sea, an artificial pocket of dry land, named the Tektite Project, built specially to accommodate and facilitate the study of marine life (Pauli and Cole, 1970). They spent 60 days living and studying the sea in there, engaging in excursions out into their surrounding environment, using scuba equipment to study the aquatic flora and fauna around them. This project, and its successor Tektite II, provided valuable insights into both the human condition and marine environments.

Elsewhere, an orb-web spider sits at the centre of its silky lair. It grows hungrier, and tightens certain strands on its web in order to change how the vibrations of its would-be prey travel along the threads to it. This environmental modification changes how sensitive the spider and web system is to flies of different sizes, as well as to other sources of vibration which might seem like dinner but aren’t. The behaviour of the spider and the web are (almost literally) intertwined: moving an orb-web spider to tighter webs makes them more reactive to smaller prey (Watanabe, 2000; Yong, 2022).

Each of these situations is a (perhaps overly) dramatic demonstration of a theme I explore in this chapter: the interweaving of systems which support the survival of organisms, and systems which support their ability to understand and

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[108] The project, perhaps even more forebodingly, failed due to social problems amongst the participants, as well as problems with the soil (Rose, 2020; Alling and Nelson, 1993).

navigate their environment, that is, the interweaving of the ecological and the epistemic. Some accounts of scientific practice have begun to bring these two together, offering an ecological twist on existing explanations of science as a social process (Rouse, 2014, 2023a; Lala, Feldman and Odling-Smee, 2023). Several authors have already metaphorically or literally applied the ecological concepts and terminology to scientific practice: Rouse (Rouse, 2023a, 2014, 2015), whose ideas I build on here, does so the most explicitly and in the most detail, using a jointly biological and social lens to examine scientific activity. Several others too: Lala, Feldman and Odling-Smee (2023); Gupta et al. (2017); and Feldman, Odling-Smee and Laland (2017) also do so, marshalling the tools of socio-ecological study to examine the nature of science itself, specifically areas of biology focused on the concept of niche construction. They argue that jointly cultural and biological studies of humanity offer insight into the spread and application of norms, which has specific relevance to the study of values in science (Lala, Feldman and Odling-smee, 2023, p.16). Lala et al. also draw connections with philosopher of science Thomas Kuhn, who spoke of scientific paradigms (treated by Lala et al. as a kind of conceptual niche), but who also explicitly drew connections between ecological and scientific niches too, albeit not in an entirely satisfactory way (Kuhn, 1990; Renzi, 2009). Here I explore further the socio-ecology of the interactions of organisms in scientific contexts, including the scientists themselves. I look specifically at the context of coral science, a science famously concerned with the survival of its study organisms.

In doing so, I examine two broad groups of questions about science: first, what is coral science, and what is good coral science? In answering this I use an ecological perspective but build on socially oriented theories of science. As has been noted in other areas, like molecular biology (Lee and Helgesson, 2020), I show here that different forms of value shape and pull on the processes at play in coral science, and in turn shape what counts as coral science, and as good coral science. This offers an opportunity to synthesise some of the previous chapters of this thesis, and to answer a second question: which forms of value are relevant to coral science, and what roles do they play? I show here that coral science sits at the intersection of a number of different considerations: ecological, epistemic, economic, affective, and more. So far I have offered more in-depth examples of the various forms of value possessed by coral reefs, and how they impact both the reefs and the study of them. Here I present the bigger picture: one of science as a process aimed at the flourishing of a set of living systems, including organisms, species, and ecosystems, as well as the social systems relating them. People involved in this process respond to shifts in socio-ecological conditions by shifting the emphasis they put on certain activities, thereby helping to maintain the assemblages and practices constituting coral reefs and the socio-ecological systems they form parts of, including coral science itself.

1.1 Socio-ecological value theories

Throughout the thesis so far I have examined several different modes of articulating the value of reef systems. All of them describe the ways organisms and their environments interact and can be considered valuable. The traditional ethical framework of intrinsic and instrumental value - which respectively describe the value something has regardless of its utility for other entities (or value which is non-substitutable, or a suite of related notions covered in chapter three), and the value something provides for some specific purpose (O'Neill, 1992; Batavia and Nelson, 2017; Justus et al., 2009) – have had enormous influence over environmental ethics and related disciplines. I also focus on ecosystem services and functions, which capture the benefits an ecosystem provides for human wellbeing, and more general important features of an ecosystem for supporting itself or living entities interacting with it, respectively (Costanza et al., 2017; Jax, 2005). These frameworks regularly help scientists and communicators capture and articulate the importance of ecological systems in both social and ecological terms, and have served to bridge gaps between disciplines normally separated by the natural-social science gulf (Gould, Adams and Vivanco, 2020; Jax et al., 2013; Jax, 2005). Finally, I also build on the relational value framework, a diverse set of ideas unified by a desire to describe nature in a more nuanced sense than narrow interpretations of traditional formulations of modes of valuation such as 'intrinsic', 'instrumental', a 'services', and in terms which are related more deeply to the meaning environments have for specific forms of life (Chan, Gould and Pascual, 2019)[109]. For more on

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[109] Many other value frameworks have recently emerged in sustainability sciences which there is not space to include here, but how such frameworks relate to values in science is an interesting area for future analysis. For example, the life framework of values offers an

relational value see ‘Value as relational’ in the introduction; chapter three where I offer nuanced and enriched notions of intrinsic, instrumental, service and function value; and chapter four where I show that non-human valuation can be incorporated into scientific processes too.

Each of these frameworks offer interesting possible points of connection between scientific practice on one hand and socio-ecological activity on the other, scientific practices being a particular kind of organism-environment interaction. By bringing these value theories from various disciplines – including environmental ethics, economics and sustainability science – into dialogue with theories about organism-environment interactions and theories from philosophy of science, it is possible to produce a more ecologically-informed account of coral science as an activity, and use that to better understand the role of value in coral science. It is this I do throughout this final chapter.

2. What kind of activity is science?

2.1 Traditional views of science

In this chapter I look at two key questions related to coral reef science, which recapitulate questions asked more broadly in philosophy of science: first, what distinguishes coral science from other activities (both normatively and descriptively)? Second, what role do different forms of value play in these activities? In general, such questions have been asked in increasingly sophisticated ways, involving appeals not just to reason, rationality and truth but also to social features of science, such as group interactions, institutional structure, and non-epistemic values, i.e. factors beyond simply the search for knowledge (Longino, 2019).

One way to describe and define scientific activity is to treat it purely as a rational and progressive process, whereby the success of people (individual scientists, research groups) and products (scientific theories, practices) are all tightly tied to how truth-conducive their work is (Dupré, 1993, pp.233–234). Many of the developments in our recent understanding of how science works have come from recognition of its social character, that is, recognition that it is a product of

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interesting bridge between the boundaries of entities and the way value relations between them are expressed (Connor and Kenter, 2019), and the nature’s contributions to people framework tries to move beyond some of the problems of ecosystem services (Díaz et al., 2018). For more on the terminology used for environmental value descriptions see Raymond et al. (2013).

work done by people interacting. In doing so, they go from treating science as some self-correcting process separate from society and from the whims and wants of the humans conducting it, to a process involving all sorts of social considerations. Thomas Kuhn – a genre-defining philosopher of science – tells us for example that scientists may choose between theories based on a variety of considerations (simplicity, fruitfulness, accuracy, etc.), and that their own understandings of the world will change how they do this (Kuhn, 1977). Karl Popper, who offered another well-known and highly cited account of science, argued that science progresses through scientists showing one another's theories to be false, through a process which is simultaneously social and evolutionary, in that it selects out the 'fittest' (best, least false) theories (Popper, 1972). Kuhn too offered the occasional biological spin on his arguments, talking about scientific theories and practices as *adapting to fit certain niches*, and arguing that scientific progress was akin to the progress seen in adaptation of organisms to niches (Kuhn, 1990; Renzi, 2009). Since then social accounts of science have flourished, looking at things like how theories and evidence come to be accepted, how evidence is characterised, what forms of value drive these processes, as well as normative considerations about how science should operate to maximise things like objectivity, reliability, fairness or effectiveness (Longino, 2019; Goldman and O'Connor, 2021; Harding, 1995; Douglas, 2000; Bloor, 1991).

During this process, the roles for values in science have been examined extensively, something facilitated by looking at connections between science and its social context (Elliott, 2022). Many taxonomies of such value have emerged, but notable is the epistemic/non-epistemic distinction. Epistemic values are those deemed to be related to truth, such as the values of predictive accuracy, internal consistency, simplicity, or explanatory power (de Regt, 2020). The role of these in science is taken to be relatively unproblematic, or as beneficial, even despite difficulty defining and articulating some of them[110] (Elliott and McKaughan, 2014). Such values are also taken to be of primary importance compared to other values in science (Elliott and McKaughan, 2014). More contentious are non-epistemic values. These are ideals which are not obviously conducive to truth, that is, they involve considerations beyond

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[110] Simplicity, for example, is not easy to define satisfactorily (Baker, 2022)

knowledge production for its own sake, for example social or political ones (Elliott and McKaughan, 2014). Examples include ethical ideals (e.g. fairness), aesthetic judgements (e.g. beauty or ugliness)[111], or religious or conservation-oriented values (Elliott, 2022). Some non-epistemic restrictions on science, such as ethical constraints, are widely accepted. Further non-epistemic constraints may be seen as negatively impacting the process of science, skewing it away from important epistemic goals (e.g. Vellend, 2019). Alternatively, non-epistemic values may be important and beneficial features of the scientific process (Elliott and McKaughan, 2014; Jones, 2021), and the exact role of non-epistemic values in science will depend on the specific context (Elliott, 2022; Douglas, 2000). Others have also challenged the distinction between epistemic and non-epistemic values (Rooney, 1992).

The key point here is that once science is seen as a social activity – that is, one performed and influenced by people – it becomes clearer that it is subject to a whole range of influences, and has effects beyond simply the search for truth. Given that it is performed by people, it is easier to see how it may be driven by a range of non-epistemic considerations, such as those derived from it being embedded in and influenced by social, political and economic systems (e.g. Shapin and Schaffer, 1985; Sunder Rajan, 2006). Even truth-adjacent considerations such as intelligibility and understanding are more easily understood when the interests, capacities and contexts of the relevant social agents are included (Potochnik, 2015; de Regt, 2020). Both sociology of science and socially-oriented philosophy of science have thereby opened up opportunities for discerning the influence society has on science and vice versa (Longino, 2019).

One of the long-standing questions in philosophy of science which has been somewhat wrapped up in this movement is the question of what distinguishes science from non-science (called ‘demarcation’). This was the question which drove Karl Popper to postulate his famous falsification criteria (Popper, 1972). Others have subsequently tried to salvage demarcation criteria in the face of challenges (Lakatos, 1978), or have else given up on or refined the demarcation project, which is beset by problems related to the sheer diversity of forms of

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[111] Although the relationship between aesthetics and truth is a complex one. Simplicity, again, is often associated with truth, but could be considered an aesthetic consideration (Ivanova, 2017).

science, which makes the use of a single criterion for their demarcation impossible. Within the refining camp, one move has been to argue that instead what is more important is the question of what counts as *good* science (Dupré, 1993). Abandoning hope of single criterion for this allows instead for context-specific and virtue-based accounts of what makes for good science (I have pursued the same strategy in the second chapter of this thesis when looking at what makes for a healthy reef. As I discuss later, the connection between good coral science and healthy reefs is more than analogous.) I think that this set of questions, about the nature of science, the nature of good science, and the role of values in science - having benefited from sociological analysis and consideration of personal, interpersonal and societal factors - can also benefit from the proper inclusion of an ecological lens.

2.2. Science as socio-ecological

It is common to separate out biological or ecological from social or cultural systems, i.e. lifeforms from forms of life (Helmreich, 2009, p.6; Rouse, 2023a, chap.1) We often refer to non-human entities in biological language, as animals, plants, ecosystems, microbes, or organisms (although these of course have social import too). We also tend to think of humans in social terms, as people, as friends, as parts of families, as performing social roles, as parts of societies or economies. Traditional academic disciplines may also divide things along similar lines (as with the ‘social’ and ‘natural’ sciences). This thinking makes it easy to ignore the ecological features of human behaviour, such as human impacts on their immediate environments, and on the assemblages of living systems they co-exist with (Rouse, 2023a). Ignorance of our ecological context is a recurring theme in many of the most pressing problems facing our species (and indeed many other species), almost enough to not require examples: climate change, pollution, soil erosion, biodiversity loss (Fabregas-Tejeda and Vergara-Silva, 2022). The list goes on, whilst humanity may not.

There is opportunity in this amnesia. It represents underexplored regions of philosophical interest. By treating science as simultaneously an ecological and social activity, i.e. one which involves social organisms shaping environments in ways which suit goals which have both ecological and social elements, it is possible to make a similarly enriching move as the one made by advocates of social accounts of science. I am not going to attempt to strictly define and delineate the social and ecological here. It is precisely the difficulty of doing this which motivates this chapter and thesis. Suffice to say that a socio-ecological approach includes personal, inter-personal and other human considerations alongside considerations of the other living systems we inhabit, cohabit with, and are inhabited by.

By looking at the considerations above, a richer picture of the nature of coral science can be drawn, one which includes the ecological *and* social contexts and impacts of scientific processes. As well as including desirable epistemic and social outcomes, socio-ecological ones can also be considered, i.e. those related to the composition of the environment and its impact on living systems within it, including non-human ones. Looking at simultaneously social and ecological dimensions of living systems has proven fruitful elsewhere, including in the two key areas I focus on here: coastal and marine environments (Refulio-Coronado et al., 2021) and humans themselves (Laland, Odling-Smee and Feldman, 2001; Odling-Smee, Laland and Feldman, 2003; Lala, Feldman and Odling-smee, 2023). Likewise, in the study of value in ecosystems, inclusion of both ecological and social entities and forms of value allows for a more complete picture (Deplazes-Zemp and Chapman, 2020; Gould, Adams and Vivanco, 2020; Woodhead et al., 2019). Much innovation has taken place in this field, allowing for a rich vocabulary for describing the significance of different parts of nature in the context of jointly social and ecological systems (Stålhammar and Thorén, 2019; Gould, Adams and Vivanco, 2020).

Other disciplines, such as evolutionary biology, have made further strides into understanding the living world by incorporating understandings of ecology (Odling-Smee, Laland and Feldman, 2003). Eco-evo-devo, i.e., ecological evolutionary developmental biology, is a rapidly growing area of scientific research which has helped develop and refine our understanding of interactions between living systems. Niche construction theory in particular has allowed for the agency of organisms, species and other living systems to be incorporated into biological theory, drawing less of an unwarranted distinction between humans and the rest of the living world (Turner, 2002; Laland, Odling-Smee and Turner, 2014). Bolstering evolutionary understandings with ecological and sociological considerations can help explain many processes more effectively

(Lala, Feldman and Odling-smee, 2023), including the process of coral science itself.

This offers an opportunity to build on previous attempts at evolutionary and ecological epistemologies, such as those of Kuhn and Popper (and the many others who have also brought evolutionary theory to bear on scientific processes (Bradie, 1986)), but with the benefit of the richer understanding of organism-environment interactions granted by modern ecology and evolution (as outlined in e.g. Kendal, Tehrani and Odling-Smee (2011))[112]. Given that socio-ecological analyses have been fruitful in many other domains, and that accounts of science thus far have often used both social and evolutionary theories to their advantage, it is important to look in more detail at how modern ecological (and eco-evo-devo) theory may help in understanding science itself too. After all, science and social systems are a part of the world they seek to study[113], and the evolutionary theories previously applied in order to better understand science itself have since been developed much further. As such they are now much better placed to synthesise social, ecological and evolutionary processes, and to highlight underappreciated aspects of science. It is niche construction theory, along with socio-ecological value frameworks, that I will use to produce a more ecological picture of science here, extending previous applications of ecological theory to science and connecting them with theories about value from socio-ecological contexts (such as environmental ethics).

3. Niche construction theory

3.1 Niche Construction

Joseph Rouse (Rouse, 2016) has offered a useful step in the direction of a socio-ecology of science. On this view, science, as a process which shapes the

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[112] Both advocates and detractors of niche construction theory have used it to analyse and evaluate science itself (and, if this situation was not already sufficiently recursive, they also specifically analyse niche construction theory as an example of niche construction (Gupta et al., 2017; Lala, Feldman and Odling-smee, 2023)). The irony here being that detractors of niche construction theory, in applying it to criticise itself, demonstrate how it may be useful in analysing the structure of science.

[113] This recognition is also the driving force behind the recurrently popular meta-discipline of scientific studies of science, currently being reincarnated through things like ‘Research on Research’ (Ioannidis, 2018). The overall trend can be considered one of meta-naturalism, i.e. of understanding science using broadly speaking philosophical and scientific methods (Rouse, 2023b). These are all manifestations of Hammer’s Maxim – ‘when you measure, include the measurer’ (Hammer, 2021).

environment in different ways which then persist and may be passed on, is a process of niche construction (Rouse, 2016). A niche is, broadly speaking, the environment of a living system which is relevant to it in some sense; that is, those environmental features which are tolerated by it, conducive to its survival (or some other goal, see below), or influence the selection of it through natural selection (Odling-Smee, Laland and Feldman, 2003). This definition is broad because the niche concept takes on slightly different meanings depending on the context (See Trappes (2021); Dorninger et al. (forthcoming)). Niche construction theories are those oriented around the idea that living entities produce and alter niches, either for themselves or others, usually along with the idea that such processes are relevant to the evolution of the system in question (Trappes, 2021; Odling-Smee, Laland and Feldman, 2003).

In building, maintaining, investing in, and working in laboratories, field sites, equipment and social structures, humans construct environments which allow them to manipulate natural phenomena so as to make them more understandable. This is a core part of the scientific process: Bruno Latour argues Pasteur did this by bringing anthrax into his laboratory (Latour, 1993), and it is what coral scientists do by bringing coral into theirs (or their labs to the coral, as is common). What this process enables is both a conceptual and embodied understanding of a phenomenon which in turn enables further prediction, control and understanding related to it (the intertwining of the embodied and conceptual; and understanding and intervention, being a common theme in biological sciences (Leonelli, 2009)). By doing so, science allows for a form of niche construction which is future-oriented, not only responding to the current conditions humans find themselves in, but actively aiming towards possible futures (Rouse, 2016). Through the careful design and use of sets of scientific laboratories, equipment, behaviour and experiments, and the inheritance of these sets, scientists produce and alter concepts which allow them to understand, intervene in and shape the world more effectively. Science, then, to paraphrase Einstein, is a refinement of everyday *activity*. The difference between scientific behaviour and behaviour of simple organisms is in the use of concepts to articulate aspects of the world into more manageable chunks which can then be manipulated. This enables scientists to not only shape their immediate environments, but to consider ways environments might otherwise be and ways to bring these possibilities into existence.

So, niche construction here connects science directly to ecology and evolutionary biology. But it also connects it to economics and sociology: scientists, as in most other professions, must usually work to survive, and are also subject to a variety of social forces. Scientists also shape their environments in ways conducive (or not) to the survival of other organisms and living systems. The socio-ecological value frameworks I have examined throughout this thesis can help understand coral science as a process: which valuable features of reef systems are being targeted here? Which modes of valuation are being employed? Functions, services, intrinsic and instrumental value may all be relevant here. If these frameworks can be used to describe the ways in which aspects of environments are valuable to organisms, and coral scientists are to be seen here as organisms embedded in special kinds of socio-ecological environment, then these frameworks can provide another way to describe and examine the roles played by value in science. This offers an ecological corollary to the sociological and philosophical work done on science so far. If we want to understand science in a thoroughly naturalistic way, i.e. as the behaviour of entities which are simultaneously lifeforms and engaged in forms of life, i.e. people, organisms and parts of larger entangled multispecies life cycles and social systems (Rouse, 2023a), the questions to answer are these: whose niches is science aimed at constructing and why? What forms of value drive science as a set of practices?

3.2 Key concepts in niche construction theory

The next step is to understand more about niche construction theory, which I will apply to coral science itself in order to better understand it. The terms *niche* and *niche construction* are used in quite a large number of ways. Here I rely on concepts taken from a few authors who use them in ecological and social contexts (Odling-Smee, Laland and Feldman, 2003; Rouse, 2023a; Dorninger et al., forthcoming; Trappes, 2021, 2022a; Aaby and Ramsey, 2022).

There are several relevant features of niches and their construction here. First, what Trappes et al. call the ‘focal entity’ (Trappes, 2022a). This is the beneficiary of the niche, i.e. the entity whose survival is chiefly impacted by the modification of their relationship with their environment. These entities are usually organisms, species, or populations[114]. Due to the ubiquity of symbiosis, niche construction often includes roles for multiple organisms or species, and some of the literature explicitly recognises this (Chiu and Gilbert, 2015; Turner, 2002; Lala et al., forthcoming, p.2). Notably, niches of different entities may prop one another up (or even expand one another) through facilitation, i.e. helping make conditions more suitable for one another (Bruno, Stachowicz and Bertness, 2003; Dussault, 2022). In cultural contexts, groups of organisms, such as a lab group in a scientific context, may be the focal entity, with their shared environment constituting the niche (Lala, Feldman and Odling-Smee, 2023). However, mixed-species sets of organisms, or even entire ecosystems, are not commonly referred to as the focal entities of niches in themselves, but rather are made up of multiple niches with different focal entities.

The next consideration is which entity is doing the construction. The constructor need not always be the focal entity, but often will be. So a coral may help build an environment which provides benefit to itself, but this will also impact reef fish which need such environments to survive. Corals and other species are often described as ecosystem engineers, i.e. entities which shape aspects of their ecosystem in ways relevant for other organisms (Jones, Lawton and Shachak, 1997)[115]. Lots of entities have impacts on the environments of others, ranging from trivial to essential contributions to survival (or some other goal). There are also cases where organisms construct one another's niches reciprocally, or where living systems can be considered as one entity or multiple entities depending on which features are being highlighted.

Finally, niches are aimed at a goal, typically survival or persistence of the entity in question. So, for example, niches may be the conditions which support the persistence of a species, or an organism. Evolution-oriented conceptions will focus on supporting fitness of an entity, or its ability to reproduce (or persist,

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[114] People also talk of the niches of viruses (Rouse, 2023a), and of cells (e.g. cancer and stem cells (Li and Neaves, 2006)), so quasi-organisms and parts of organisms can also be considered focal entities in some contexts.

[115] Also related to the concept of keystone species. Note that ecosystem engineering and niche construction are not the same, having different connections to evolutionary and ecological theory, but for the purposes here the point is simply to note that both recognise that entities can shape their own environments and those of others. Niche construction theory puts more emphasis on the inheritance of such environments, and that these environments thereby cause evolutionary change (Barker and Odling-Smee, 2014, p.192; Lala et al., forthcoming, chap.9)

given the right account of evolution). Other niches focus on the development of an organism, or the ability of a species to establish itself somewhere. There are some less traditional niche goals: an important one here is niches which are conducive to the flourishing or thriving of an organism[116]. These are the conditions under which a system is able to flourish, that is, do more than survive, and reach beyond mere survival to embody some of its greater potential. This is easier to define in human cases, but may also be considered in cases of other living systems, especially those which demonstrate significant complexity and plasticity, i.e. which can engage with the world in a greater variety of ways, and where such ways can be more or less successful. Niche construction theory - and extended versions of evolution more generally - open up space for the success or fitness of an organism to be evaluated according to a range of different criteria beyond simply number of offspring or amount of genetic material transmitted by broadening out the focus of biology to include multiple channels of inheritance (such as behavioural, epigenetic, environmental and cultural modes) (Lala et al., forthcoming; Odling-Smee and Laland, 2011, pp.223–224). This makes it easier to consider, for example, the lifespan of an organism, its ability to grow and transform, or the suffering and pleasure it endures, whilst still retaining a focus on biological considerations. In Rouse’s framework, specific forms of plasticity, such as behavioural plasticity, may be more amenable to analysis in terms of flourishing, but even comparatively simple organisms can have their environments evaluated in terms beyond simply survival and death (Rouse, 2023a)

Niches may also be discussed in a cognitive sense, that is, as an environment in which an organism is able to process information about the world, or able to sense and respond to some stimulus. This is the cognitive niche of an organism (Bertolotti and Magnani, 2017). Others have discussed epistemic niches, i.e. the environment in which some epistemic agent can know something (Sterelny, 2003, chap.8). Such niches are also related to conceptual and scientific niches, which may refer to the environment in which scientific concepts or practices are

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[116] Flourishing is not explicitly discussed in niche construction literature, although there are lots of ways in which it might be understood implicitly (for example in terms of optimal and sub-optimal conditions for organisms). It is also raised implicitly in Rouse (2023).

perpetuated, as kinds of cultural trait (Lala, Feldman and Odling-Smee, 2023)[117].

Above are the main concepts I use to analyse coral science, although I refer back to a few other concepts later on: fundamental vs realised niches, i.e. the conditions under which an entity can exist, and those under which it actually does exist, respectively; niche construction, choice, and conformance, i.e. directly modifying your environment, changing your relationship to your environment (e.g. by moving to a new one), or modifying your own phenotype in order to change your relationship to your environment (Trappes, 2022a; Aaby and Ramsey, 2022); and niche destruction, i.e the modification of an entity's environment in a way which negatively impacts its ability to persist, or some other goal.

4. Which niches are relevant to coral science?

It is now possible to look at which niches are being constructed in coral science - if it is to be seen as niche-constructive activity – and which forms of value are relevant to such processes. The first, and simplest, place to look is the niches of the individual organisms present: humans, coral, and others.

4.1 Science as supporting scientists or other reef organisms

4.1.1 Scientists

In one sense, coral science helps perpetuate the existence and ways of life of coral scientists. Just as with any other profession, scientists must work in order to survive, and so scientific activity is tied up in the survival of its practitioners. Clearly, this is not the main function of coral science, or even usually an explicit aim, but is important to consider. Science as a process is underwritten by the division of labour found throughout the economy, and relies in various ways on economic value, for example in the funding of research (and therefore the incomes and subsistence of scientists); and through the marketisation of scientific outputs, be them direct or indirect (Pinel, 2020). In a basic sense, then, scientific activity involves a kind of niche construction for scientists, enabling them to continue living, providing them with food, shelter, and the other

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[117] The exact relation between all of these forms of niche is complicated, likely contentious, and not relevant here.

necessities of life, through the economic division of labour in society. Whilst there are many more important and interesting features of coral science, these basic considerations do help shape careers (and scientific activity), producing a kind of choreography of interests and opportunities that many academics (and people from a range of other professions) will no doubt be familiar with (Helmreich, 2009, p.52). This was a common theme in interviews:

Quote 113

> “EJ: So how did you end up studying coral reefs?
>
> 1001: So I did do my undergrad in biosciences, but I always knew that I wanted to do marine biology. So for my master's, I did a marine biology degree. And I guess, during that I got in contact with coral reefs, because we had a course and also an excursion to the Red Sea. And I just thought it was a fascinating ecosystem, very diverse, very complex. I also learned to dive while doing my master’s during a holiday in Thailand, so I thought it was a cool thing to do. And so I asked, basically, I asked the professor of the coral reef course if I could do my master’s thesis with him. And so we found me a project and he offered me a PhD. …
>
> EJ: So what led you to work more on the reef structure stuff that you're doing now? And [away] from the ecology stuff?
>
> 1001: …Basically, this job, where I got a job, because yeah, there's not so much jobs out there, for us postdocs. And I mean, when I read the posts, I thought it was really interesting.” 1001

Quote 114

> “EJ: And what made you kind of want to study those reefs specifically, the reefs you do study and the aspects of them you study?
>
> 1025: I always liked the sea... I grew up in a city [where] there is a huge sea just close to my parents’ house. And I used to go fishing and scuba diving. And it was always part of the culture, for my family and for my culture. So doing science was something new…
>
> [discussing choice of specific reefs to study]
>
> … Well, the reefs by themselves, it was kind of opportunistic, then, the beginning of my career, I entered into some projects that, you know, I was just trying to find an opportunity. … I had a professor that made a project to study the reefs from the entire coast. So I travelled across the entire coast studying so many different reefs. So then when I became a professor, I choose two of my preferred sites … I decided to concentrate some of my efforts there, not only because of scientific aspects, but also because of personal aspects too.” 1025

So, just with most other professions, economic opportunity shapes activity, because the survival of the person doing the work is a consideration. But beyond personal and professional survival, coral scientists also construct a niche for themselves in terms of being able to engage in specific sets of practices which constitute a way of life they desire. In this sense, coral scientists benefit from their work beyond simple payment for it. The activities engaged in by the scientist are often valuable in themselves, beyond the value of the products they produce, or the value accruing to them through payment for their work[118]. Both of the quotes above explicitly take this into account. In Quote 113, the interviewee stresses that they always wanted to do marine biology, that they found coral reefs fascinating and enjoyed scuba diving, and that the project they most recently joined was a very interesting one. In Quote 114, the speaker shows a similar pattern whereby their personal interests (diving, fishing) and childhood environment made a sea-oriented job desirable. Then an interplay of scientific and personal aspects drove their later choice of study sites. So a key part of coral science is that it provides an opportunity to engage in a set of practices which are valuable to the coral scientist, that is, it allows them to construct niches in which they can both survive and flourish. Note also that this relates directly to the affective level of variation in baselining that was discussed in chapter one, which is influenced by the kind of personal experiences and relationships scientists have with different environments.

Allusions to this were very common throughout interviews, with many scientists mentioning the satisfaction they take from aspects of their work and environment:

Quote 115

> "I studied as a marine biologist, really, because during my teenage years, I got into surfing and fishing and snorkelling and diving. And like the idea of a creative career that I could choose my destiny with, but that would keep me in the ocean." 1002[119]

Quote 116

> "But I'm often diving on the reefs, or showing students coral ecology, and you see whales swim past and dolphins and whalesharks and turtles and things like that. So even though I, my research focus is on something very, very small, I actually get to enjoy and embrace and value everything else which is going around, which is quite a powerful and empowering thing as well in its own right." 1015

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[118] In many cases the tools and procedures of science can be as or more important for science than the outputs such as theories and data (Leonelli, 2009, pp.194–5)

[119] Note that here we are literally talking about the environment the participant lives and spends time in, i.e. they are talking about relocational niche construction, or niche choice.

Quote 117

> “I was always fascinated with things in the ocean. So it was kind of a natural interest.” 1018

Quote 118

> “Oh, to start with, it's probably because I went diving with my dad when I was about 14. In the south of France. I was really hooked on... how amazing things were underwater, how completely different to anything you see on land. … so I was messing around in the sea, either sailing or canoeing or swimming. So I've got an affinity for it.” 1017

The values driving the activity in this context are derived not from some product, or end state, but throughout the practicing of coral science. This is not unique to coral science. Many human practices are valuable throughout their performance, rather than just for what they produce at the end (Rouse, 2023a). In the context of professional activities, elements of this are sometimes captured in the notion of job satisfaction. Here though, this stretches beyond professional life, particularly as the distinction between work and recreation is blurred in many of the activities of marine scientists. As is visible above, it is common for coral scientists to start doing coral science due to a love of marine activities, and this continues throughout their lives, including during work. Scuba diving is the best example of this, as an activity which many coral scientists enjoy and which acts as a catalyst into joining marine science in some cases. Not all coral scientists enjoy diving, but it is recognised as common that they do, and a perk of the job in many cases[120]. So here, whilst coral science as a professional activity does construct a survival niche for humans engaged in that work, working on a reef also allows scientists to engage in fulfilling practices, i.e., it amounts to the construction of a niche which contributes to their own flourishing.

But there is more to this, even from the perspective of coral scientists. The practices of coral science are also self-sustaining in a sense, allowing coral scientists to continue working *as coral scientists*. As with many other activities,

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[120] One interviewee, after outlining the parts of the job they did like, said this: “But I'm definitely not someone, and many of my colleagues are, who have a foundational fundamental drive to be underwater all the time.”… [I don’t have the] “Jacques Cousteau thing”.’ 1026

coral science must be sustained by the relevant resources, particularly financial support. Scientific outputs such as articles are used to help drive acquisition of professional and personal resources, and to ensure future career success. These considerations come up frequently in studies looking at why scientists publish (Hangel and Schmidt-Pfister, 2017). These activities are bound up in the success of the organisations they are embedded in, for example lab groups and larger research institutes, again a commonly mentioned factor driving scientific publication (Hangel and Schmidt-Pfister, 2017). Here there is also self-oriented niche construction at the level of the laboratory, or groups of scientists, with research activity depending on grants[121]. Part of this process involved producing valuable scientific outputs, which may also be used to generate value elsewhere, such as health or economic value through translational research (Pinel, 2020). In this context, laboratories, and scientific activities more broadly, are sites of production of value in various ways, including personal forms of value through credit and reputation, and economic value through licensing and selling of products, as well as through research grants (Pinel, 2020). These forms of value are of the traditional instrumental sort, serving the purposes of some entity, in this case the coral scientist or larger institution they are embedded in. The scientist here acts as caretaker of the scientific environment and the (epistemic) community associated with it, i.e. the groups of people involved in the maintenance of the scientific institution (Knorr-Cetina, 1999, p.38; Meyer and Molyneux-Hodgson, 2010, p.4). In niche construction terms, the scientist or institution is the focal entity of the activity, and one of the goals towards which their activity is oriented is a mixture of personal and institutional survival and recognition.

So coral science enables the continued existence of coral scientists, that is, humans engaged in a particular set of practices, many of which are valuable in themselves and which also produce valuable products. Be they epistemically-oriented (e.g. discovery, publishing), more unusual (diving, snorkelling), or more mundane (reading, attending conferences), many of these practices are an important part of the lives of coral scientists, and coral science as an activity enables these to continue. But even this initial picture suggests that this is not just about the enjoyment or utility of the coral scientist. As I have shown in the

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[121] See Coral Funders, (2020) to get a sense of the grant landscape in coral science

last two chapters, and as is visible in the quotes above, coral science is not a purely self-oriented or utilitarian activity, driven only by the satisfaction derived from activities like diving or discovering things. The value of these activities depends on the relations coral scientists have with their environment and other living entities, the attitudes and experiences they have towards and with them, and the webs of mutual dependencies between parts of the systems in question. The instrumental and the intrinsic are difficult to separate. Even in the context of the benefits to scientists, then, coral science is not simply self-facing. Coral scientists get value from their work in part due to the fact they care for a wide range of other entities involved in it.

4.1.2 Other organisms

Conceiving of coral science as primarily aimed at constructing and maintaining the niches of coral scientists (and associated institutions) leaves much out of the picture. To start with, coral science often does not benefit coral scientists: some aspects of coral science, particularly in recent years, are at best mundane[122] and at worst deeply unpleasant[123]. Coral science as an activity also fails the ‘millionaire test’ for helping detect primarily self- and survival-oriented activity. Whilst for many jobs, many workers would pretty immediately stop performing them were they to have their survival needs met (before even mentioning luxuries) – e.g. if they were to become millionaires – this would likely not be the case for many coral scientists. Indeed, they may give up their spare time and sacrifice comfort in order to do more work. This points towards another important consideration for coral science, then, namely that it is supposed to be of benefit to the corals themselves, and other relevant organisms[124]. This outward oriented sentiment is reflected here:

Quote 119

> “And so having been driven from a very young age to, to work and be interested in protecting nature, I think it was perhaps slightly inevitable that at some point,

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[122] As articulated by an interview participant discussing their childhood perception of marine biology “But I thought a career in marine biology basically meant like surfing and fishing. I didn't really know at the time, it meant, like, email, you know?” 1023

[123] The unpleasantness has been well-catalogued by Braverman and others, including through notions such as ‘ecological grief’ (Braverman, 2018, chap.2; Gordon, Radford and Simpson, 2019; Conroy, 2019)

[124] This test is only indicative, and not conclusive. It could also point towards the job being enjoyable, for example due to curiosity or passion for scientific activities themselves. These are important parts of the scientific process in coral science, but are tied into care for the relevant organisms, species and ecosystems too. With thanks to Rose Trappes for pointing this out.

> I'd have my attention caught by reefs, because I think they are the pinnacle of that question, of that challenge” 1003

A core feature of coral science is articulated here: it involves “*protecting nature”,* with coral science specifically being “*the pinnacle of that challenge”*. The protection of non-human entities is a key part of what coral science does. Whilst coral science is driven by personal motivations, and is related to the niche of the individual coral scientist, it is also strongly focused on understanding and supporting some other specific organisms and environments. Here, these are intertwined. The speaker was motivated to follow their personal desires, and to get a job which allows these to be acted upon, but these desires are specifically tied to caring for nature. This attitude is common throughout coral science. There is of course the obvious requirement that coral science must allow coral scientists to survive (or else be at least compatible with some external economic system which allows for this). But if it only does this, and nothing else, it is liable to serious criticism from other coral scientists, will not be considered coral science at all, but rather a kind of scam pretending to be coral science:

Quote 120

> “I've been to places where they've tried to grow corals, restore corals … and that's not working … And it's annoying actually, because it's a bit of a scam. They know it doesn't work but it does attract funding. And so it helps the marine station go along and it … helps their profile and stuff as scientists. But the fact that it's not working, I think is diverting goodwill and cash, away from something that might work. We've got to be aware of that, I think. I'm not saying no coral reef restoration works, but this particular example wasn't working at all, and yet they kept doing it.” 1016

This quote traces the niches I have examined so far. The speaker states that certain activities, such as those described above, can support coral scientists in terms of their livelihoods, practices, and careers, as well as supporting the institutions they are part of. But they may not support corals or other non-human organisms. Here, the importance of the niches of other organisms is made clear. The stress in this quote is on the need for coral science to actually succeed (or at least be realistically aimed at) supporting coral and other organisms, not simply supporting coral scientists and marine stations. Coral science then cannot be simply aimed at supporting scientists, and when it is, it is subject to criticism by coral science practitioners. It ought also to contribute to the survival and flourishing of a range of other entities too. This is not simply a case of the epistemic features of the research mentioned in Quote 120 being unsatisfactory, but the ecological features too. This aim, of supporting specific organisms, was made explicit by other participants:

Quote 121

> "…So I got a bit tired of documenting demise on reefs. And I wanted to try and look into how to save reefs, rather than just be a witness to the demise and destruction. So we started working quite a lot on spawning corals and looking into ex situ spawning techniques, improving the tools available to conservationists and reef restorationists" 1015

Note that unlike the sustenance of coral scientists and science, which is a somewhat implicit result of the economic organisation of society, supporting non-human organisms is a more explicit goal of coral scientists[125]. In this quote, that aim is spelled out: the speaker worked on helping corals reproduce and wanted to try to save reefs. Through such coral spawning techniques, coral scientists aim to support coral organisms, and to ensure that their existence is a healthy one (there is also a concern for ecosystems as well as organisms, which I turn to shortly). Already this shows that socio-ecological context is relevant to the goals of science: when coral organisms are threatened or harmed, action is taken to not only understand but also to try and remedy this ('rather than just be a witness to demise and destruction'). These actions may involve directly engaging in conservation and restoration, or less directly developing tools to allow others to do it better. Even those scientists who do not believe in restoration as an effective tool still do work which helps understand how corals will respond to changes in their environment, and this is often justified in terms of helping them survive into the future, for example, by providing evidence to undergird measures to protect the environment of the coral (Morrison et al., 2020). On the other extreme, ex-situ spawning involves literally constructing artificial environments for reef organisms in order to induce them to reproduce, something which has had notable success recently, and which typically has an instrumental function, namely to replenish populations on reefs or furnish laboratories with experimental organisms (Craggs et al., 2020; Guest et al., 2014). Ex-situ conservation, i.e. growing corals for their own sake, or for longer-term instrumental purposes such as replenishing populations in the

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[125] And of coral science institutions too: the International Coral Reef Society, the largest professional organisation for coral scientists, has as its mission statement: 'ICRS promotes the acquisition and dissemination of scientific knowledge to secure coral reefs for future generations' (International Coral Reef Society, 2023)

future, is also something being increasingly discussed and advocated (Zoccola et al., 2020), especially since anomalously high sea surface temperatures in Spring and Summer 2023 caused very high rates of mortality due to bleaching in various places, including restored reefs (Coral-List, 2023c; b)

So, to summarise the points from the last three quotes, caring for nature broadly, and reef organisms specifically, is a key aim of coral science. Understanding these systems is also an important aim, and the two are not easily separable. This fits with arguments made by others that biological sciences are 'impure' in the sense that intervention on and explanation of living systems are necessarily intertwined processes, even in less drastic senses of intervention such as the use of organisms for experimentation (Leonelli, 2009). According to the underlying view of coral science I have put forward here, these considerations are recognised when assessing coral science: in at least some contexts, good coral science is that which shapes environments in ways conducive to the survival of a certain set of non-human organisms and associated biotic and abiotic systems. Good coral science aims at healthy reefs.

But this leaves a big question: which systems and organisms ought coral science to support? An obvious answer to this is coral (although the question recurs – which species of coral?), but many other entities are the focus of concerted study and support, including fish, other animals, plants and even microbes[126]. This is visible for example when discussing minimising the distress of study organisms, or finding optimum conditions for them to grow in, as discussed in chapter four:

Quote 122

> "and then in terms of model systems, for corals, we don't tend to work with model systems as much… we often bring fish into the lab, and work with simplified arenas and simplified environments. And for that we use clownfish a lot. They are very easy to breed in captivity, they're naturally fairly site attached, so that they don't get freaked out by being in a fairly small tank, because that is their natural environment to be in a small space." 1002

And such concerns were also raised in discussions about the non-substitutability of life on the reef, as in the quote from chapter three (which I

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[126] There is much work on ensuring healthy microbiomes on reefs – although this is often articulated instrumentally, so that the microbes are valuable in so far as they support the lives of other organisms: 'So we do exploration, exploratory work on assisted evolution and use of probiotics to give corals a fighting chance' 1015. See also (NASEM, 2019)

return to shortly) where a participant worried that losing reefs means losing ‘a moment in history’ filled with a unique combination of unique organisms, and likened this to losing the Mona Lisa, which could be replaced by another painting, but not the same one (Quote 83).

Both the fish in the lab case and the Mona Lisa case show a concern for constructing niches for certain organisms (clownfish in the lab, reef inhabitants in the sea). This niche construction may be for a variety of reasons: it may be tied to the nature of living organisms, which are seen as valuable in their own right, something linked by the speaker in Quote 83 to their historical uniqueness, a recurring theme in discussion of the value of nature (Katz, 2007)[127]. But constructing environments for non-human organisms may also be done for instrumental reasons, such as that it helps scientists learn about other organisms, species or the larger reef system. This is the implication of the discussion about fish in the lab, i.e. that constructing environments for clownfish within laboratories – which are used as study systems to understand phenomena on reefs - helps scientists understand them and the reef system more effectively. Here, the instrumental and intrinsic value of the reef organisms is intertwined. Fish are useful for scientific reasons, in part because we want to understand how to protect them and their environments in the wild, and so are cared for but also sometimes harmed in laboratory and field work, in order to help protect them and other reef organisms elsewhere. This is the same intertwining of the intrinsic and the instrumental, and care-driven and epistemic concerns, seen in the last two chapters. Reef organisms offer an instrumental value for both humans and other organisms, and also have their own value as living beings worthy of protection. The concern for these organisms also surfaces when discussing trawling as a method for obtaining organisms to study, briefly discussed in the last chapter:

Quote 123

> “Going down in a submersible, you collect about one hundredth of what you would collect with a trawl just rampaging over the bottom. But as a taxonomist, I would like to see as much material as I can. And sometimes I argue, it is defensible to collect using a trawl, at least to find out what's there, and

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[127] N.B. that in interviews and coral science articles, the value of non-human organisms and of non-human species is often blurred.

> necessary to protect [it]. You’ve got to know that it's there to protect it. And you’ve got to collect it to know it's there”. 1020

Here, trawling for research specimens is cast as a necessary evil only insofar as it protects the things it damages. So there is a direct concern for the welfare of the organisms being trawled, enough to cause the speaker to spell out the justification for this method in terms of a greater benefit overall to those organisms.

So coral science is aimed, in some sense, at the protection of a suite of organisms that live in, on and around reefs and labs. But this picture is not a simple one: some organisms are subject to less attention within coral science, or actively negatively valued. As discussed in earlier chapters, algae-dominated reefs, or reefs overrun by certain organisms (bacteria of a certain kind, for example), may be seen as degraded, and subject to attempts to change their composition (Rachmilovitz and Rinkevich, 2017). This is true of species such as those involved in certain algal formations, as well as bacteria, lionfish, or crown of thorns starfish, which may be considered undesirable and subject to both studies and interventions focused on reducing their prevalence or influence in a certain location:

Quote 124

> “And so my thesis and all that was looking at how crown of thorns outbreak affected the reef communities. But then, sort of during my PhD, I kind of stumbled over a side project and **worked on how to best kill Crown of Thorns starfish, which ended up being a huge side project**.” 1007

Quote 125

> “…but I've also done work on invasive lionfish. … So looking at how effective removing lionfish is, and looking at kind of different... whether within a marine protected area where you can't have fishing if you get more lionfish there. And they kind of use that as a refuge. So **I did a lot of diving and spearing lionfish for my masters**.” 1011

Or, as expressed in the conversation about microbialisation:

Quote 126

> “the more the microbes take over, the worse it is, for the most part, for human things.” 1022

The implication of each of these quotes is that not all organisms are equal in the context of coral science. Some are seen as undesirable within the context of their presence on a reef, as with crown of thorns starfish which may alter the reef system when they are too great in number[128]. Lionfish are similarly seen as disruptors of reef ecosystems when they are in environments outside of a certain historical range (Diller, Frazer and Jacoby, 2014). The disruptions and alterations these organisms induce are seen as bad for other organisms, humans included, as indicated in the quote on the microbialisation of reefs. This means that both research and actual interventions may be undertaken to prevent and reverse such alterations, as above in the case of looking at how to kill Crown of Thorns Starfish, and Lionfish[129]. Epistemic practices are simultaneously ecological, and values determine not only how things are classified by how they are treated too (Helmreich, 2009, chap.4) Here it is obvious that coral science is oriented in a way as to favour some organisms, and some arrangements of organisms, over others (with terminology such as 'native' and 'invasive' following the same pattern (Helmreich, 2009, chap.4)). The reasoning underlying this involves considerations beyond just the niches of individual organisms, including sets of organisms such as species and ecosystems.

So, some parts of reef systems may be subject to modification in order to sustain others. Algal symbionts may be modified in the hope of bestowing greater heat tolerance on corals and the larger reef system (Chakravarti and van Oppen, 2018), or corals themselves bred in order to improve the heat tolerance of the reef (Anthony et al., 2017). These changes are not simply done in the interests of the entities being modified, or of specific individual organisms, but also serve purposes at other scales, of entire species or the ecosystem as a whole. Concerns with scale are often articulated in the context of restoration, including in interviews:

Quote 127

> “And we're just talking about corals. There's a whole reef of things that rely on corals. And so that whole reef of things is going to go away too, if we can't get reefs in better shape. And I view this as the sort of the tip of the iceberg honestly” 1026

and on by high-profile coral scientists on public forums such as twitter:

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[128] See Sapp, (1999) for a detailed analysis of the Crown of Thorns problem in coral science.

[129] See the earlier chapters on reef health and baselines for an analysis of this in the context of algae and microbes.

> “Coral gardening doesn’t restore biodiversity.” (Twitter, 2020b)
>
> “But critically, reef ecosystems are comprised of tens to hundreds of coral species and tens to hundreds of thousands of other taxa (fishes, inverts, seaweeds, etc) also being impacted - nobody is even trying to grow and restore 99.99% of them. This won’t ever be ecosystem restoration.” (Quote edited to improve readability) (Twitter, 2020a)

These quotes point to other aims in coral science beyond simply helping individual reef organisms. “There’s a whole reef of things” which may be the subject of niche construction, and these may be considered as wholes themselves rather than as collections of wholes. This is why the tweeters refer to biodiversity and to ecosystem restoration, because they are concerned with entities at scales above the organism. Indeed, this is a key flashpoint in debates around activities associated with coral science: what is the potential or actual scale of influence of the activity? How many organisms will be impacted, across how large of an area and how long of a time, and how does it impact species and ecosystems?[130] So, we have another set of niches to consider here. Whilst both coral scientists and reef organisms may benefit from coral science, and whilst good coral science will explicitly aim to understand and support reef organisms, there are also other aims and entities to think about.

4.2 Science as supporting species and ecosystems

As well as individual humans and other individual organisms, coral science is also heavily focused on species and ecosystems. The human species in particular is a commonly invoked focal entity in the niche constructive practices of coral scientists, particularly via the concept of ecosystem services.

Ecosystem services – discussed earlier in the thesis - are typically defined as the ‘ecological characteristics, functions or processes that directly or indirectly contribute to human wellbeing’ (Costanza et al., 2017). Put simply, they are the processes in nature which people derive benefits from, i.e. processes which ‘sustain and fulfil’ human life (Daily, 2003, p.227)[131]. They are invoked extensively in coral science, and natural sciences generally, including in contexts aimed at political decision makers and the general public (Parks and

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[130] The issue of the scale of restoration comes up frequently too in Irus Braverman’s interviews with coral scientists (Braverman, 2018)

[131] There are lots of different formulations of the ecosystem services concept, with all or most invoking the benefits ecological systems provide to humans. Further differences between them are not relevant here.

Gowdy, 2013; Brunet, 2022), and are a common way to describe the value of reefs. Ecosystem services are often mentioned near the beginning of coral science articles to emphasise the importance of reefs, but may also appear elsewhere in the text[132].

I have argued in chapter three that ecosystem services are employed in a nuanced way by coral scientists, as part of a general interplay between instrumental and intrinsic modes of valuing. Scientists both actively embraced the dependence of humans on reefs, and criticised a view of this as the only salient feature of reefs. To return to two quotes showing these views:

Quote 128

> “But arguably, what we should be focusing on is the value that they provide to these … 500 million people who rely directly on reefs … they need them to be storm barriers… to be able to harvest their fish … so I think we … can think differently about engineering reefs to survive”. 1026

Quote 129

> “So, for example, the intrinsic value of biodiversity, the intrinsic value to humans, is not economic, … it's measured in other things, and you can't put an economic value on it. So I think [ecosystem services] can be quite dangerous. And then also just the idea that it is a service to humans, does have some intrinsic issues with it in that, … it becomes, you know, that's not what they're there for. You start to see it as a something that's... that whole issue of being put there to provide resources for humans, is not something that I think is true” 1010

In Quote 128, the aim of coral science is to facilitate the continued existence of the many humans who depend on reefs for a variety of things, such as solid and safe ground for living on, or food for eating, that is, to maintain a species-level niche for humans[133]. Furthermore, as with the individual scientist case, reefs

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[132] One scientist mentioned this explicitly:

“EJ: … so do you use the term ecosystem services in your work…?

1009: Usually in the first paragraph of the introduction

EJ: And why in the in the first paragraph?

1009: Well, the work that I'm doing, I guess it's not directly related with giving recommendations for policy or this kind of thing. … but when you're introducing your topic, if you're writing a paper, your target audience is someone who doesn't know what a coral reef is, in that first paragraph, so you tell them these are systems which are really important. They provide these key ecosystem services, or key functions.” 1009

[133] Discussing niches at this level also raises questions about which humans have control over things like the environment and scientific funding. Many of the ecosystem service benefits

undergird a variety of practices tied into the ways of life of many communities, such as through the cultural and recreational qualities of reefs, and the provision of income from them through things like tourism. They also provide other benefits through things like provision of novel chemicals for use in medicine (Moberg and Folke, 1999). Ecosystem services are a broad category which includes intangible, aesthetic, scientific, and cultural benefits, including concepts such as existence value, i.e. the benefits derived by humans as a result of something simply existing ((Costanza et al., 2017; Davidson, 2013)). As such, the various ways humans depend on (and, more broadly, benefit from) reefs is a key concern of coral scientists, and a key aim of coral science is maintaining reefs in a way which continues to benefit people.

As Quote 129 shows however, this aim is not unequivocal or unqualified. There is a recognition that ecosystem services could be problematic, particularly through their anthropocentrism, and attempts to define reefs purely as systems for providing humans resources. As explored in chapter three, one of the chief problems with ecosystem services is that they can make reefs fungible, i.e. they may imply that replacing a reef with a system which has the same impacts on local humans – in terms of specific features, such as protein provision through fish, recreational value, or ability to protect from waves – would involve no significant loss. In interviews, scientists were often opposed to this way of articulating reef value, particularly when it was taken to be exhaustive of the value of the reef. Reefs are seen as valuable in a much greater sense than simply for the tangible and fungible things they provide humans. This was the point of the discussion about the Mona Lisa, which I now return to:

Quote 130

> “I think if we were to lose reefs tomorrow... I think we'd actually lose the beauty faster than we lost the value, because I think the beauty would just be gone. And **that would be a moment in history that we could never get back**. Because sure that'd be something else that, you know, like a shallow tropical sea, it's never going to be an empty environment, there's just too much energy there. **But if we were to lose all the inhabitants of the reef, no matter what else cropped up and sprung up in its place, you know, you've burned the**

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associated with reefs may be phrased in terms amenable to the individuals and groups with more resources, because they are the ones who have more sway over scientific agendas, for various reasons (for example, medicines for various diseases of affluence might be mentioned more frequently, because these are likely to be valued the most highly in monetary terms). Those with higher income may also be more strongly factored into economic evaluations of environments, for example because they have a higher ‘willingness-to-pay’ for them.

> **Mona Lisa, you can paint another painting if you want, but it's not going to be the Mona Lisa is it? Like it's going to be different**. Whereas the difference with the value is that it is feasible to think that actually, reefs might be replaced by something else that have equal value in terms of fishing output, or in terms of coastal defence, or in some … because from a purely like, pragmatic approach, like, there's papers out there, that show actually, a degraded reef, if you fish it in the right way, can have a similar fisheries output value, than a healthy reef. And, you know, you can imagine, there's manmade coastal defences, or, maybe in some areas, you can plant some other type of coral or some other organism that dissipates wave energy in a similar way to a coral. So I think, in that sense, the pragmatic value of reefs, probably, I sort of hesitate to say it because it sounds a bit like you being a bad guy, but I think it probably isn't irreplaceable, in the same way that the slightly less measurable beauty of a reef probably is irreplaceable." 1003[134]

The point here is that whilst supporting human wellbeing via instrumental means can be seen as an aim of coral science, it is one tempered and nuanced by other considerations, and that the value of coral reefs, value which shapes coral reef science, cannot be reduced to simply the value these systems provide to the human species. To do so potentially licenses the destruction of other valuable aspects of the reef. Constructing a niche at the level of the human species is one aim of coral science, but is one aim amongst many. The prevalence of ecosystem services in coral science might at first make it seem a very human-centric science, but the nuanced deployment of the ecosystem services within coral science reveals a much broader concern with both humans and a range of other non-human entities.

This points to another aim of coral science, one tied to criticisms of ecosystem services as a framework, and paralleling the dialectic earlier in this chapter between individual coral scientists and other organisms: non-human species, and ecosystems more broadly. It is not enough to say coral science is oriented towards providing instrumental benefits to individual scientists, other organisms, and the human species. It is also important to consider the impacts on other species, and ecosystems as a whole. This is why the ecosystem service framework is often employed in diverse ways which overlaps with more

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[134] Interestingly, this seems to recapitulate Schopenhauer on death: "The deep pain that is felt at the death of every friendly soul arises from the feeling that there is in every individual something which is inexpressible, peculiar to [them] alone, and is, therefore, absolutely and irretrievably lost." (Schopenhauer, 1974, p.585) This links more broadly to the idea of intrinsic value in environmental ethics, that is, that some entities have worth simply for what they are (Batavia and Nelson, 2017). Intrinsic value is often discussed in the context of unique and non-fungible entities, as explored in chapter three.

traditionally intrinsic-value-oriented concerns, such as the non-anthropocentric, non-instrumental, intangible or non-fungible features of reefs. These features are often subject to investigation, conservation, and restoration:

Quote 131

> “The same with coral reefs, you've got … this type of branching coral allows for that type of fish, and that invertebrate to fit in**. So all that complexity, allows for these species to find their niches within that habitat and that ecosystem, and then they can thrive and contribute to the function of the entire reef**…
>
> And then, you know, if you lose coral reefs, you lose that complexity and that ability to contribute to that diversity. And so you would lose those species that rely on those coral reefs, maybe even also pelagic species [such as fish] that use coral reefs as their stepping ground before they move out into the wider ocean as well.” 1004

Quote 132

> “… and this ties into restoration a lot, that, I think it's now unrealistic that we're going to be restoring reefs to any kind of pre-industrial levels. **And so it's more looking at preserving function, which would be things like having herbivores and having predators and having those trophic chains preserved and having some kind of coral that provides structural complexity for other species, and that kind of stuff**. So preserving the functions of a pristine reef rather than the exact species and diversity of a pristine reef.” 1007

Here there are appeals to some other important beneficiaries of coral science, and to some associated aims of scientific activity. In Quote 131, the speaker appeals specifically to certain types and species of organisms (coral, fish, invertebrates), as beneficiaries of a healthy and functioning ecosystem. They also refer to the diversity of the system, and to the ecosystem as a whole as a beneficiary. So beyond constructing niches for humans, coral scientists also have concerns for the existence of non-human species, of other types of living things, and of ecosystems.

A key way this is emphasised is through the notion of ecosystem functions, mentioned in Quote 131 and discussed more explicitly in Quote 132. Here, the aim is to understand and protect specific arrangements of organisms and abiotic components, as larger systems which operate in certain ways. Hence the speakers talk about the different roles in the system: corals as contributing to complexity; herbivory and predation; trophic chains (i.e. how energy flows through the system); habitat provision. Here, ensuring certain patterns of ecosystem arrangement is the aim of the activity, with the speaker explicitly talking about intervening to guarantee them, i.e. constructing a niche at the level of the entire ecosystem. Similar ecological processes have been named as the ‘core functions’ of coral reef ecosystems in scientific literature (Brandl et al., 2019).

Ecosystem functions are often described in very broad ways, for example as ‘processes and the causal relations that give rise to them, to the role of organisms within an ecological system, to the overall processes that sustain an ecological system (which together determine its “functioning”) and finally to the services a system provides for humans or other organisms” (Jax, 2005)[135]. This obviously encompasses a whole range of processes, and when raised in discussion, these processes were – in line with the definition above - typically to do with supporting non-human species, i.e. emphasising the ability of the environment to enable them to persist, or else were related to the larger ecosystem:

Quote 133

> “And then you've got the more kind of functional ecology side of coral reefs, **which in the absence of all humans would still be there**. And so let's start with that. So obviously one of the main features is the bioengineering of corals. So they build habitat, reef forming **corals create environments that then host exceptionally high levels of biodiversity. And provide very stable, both structurally stable, but also environmentally stable environments for animals to live in, and some plants**.” 1002

Quote 134

> “In the way I think about it, I think a function is something to do with the sort of the inherent way the ecosystem is stitched together, and the way that the community of different animals and plants and organisms on the reef, work together to create a property of the ecosystem that wouldn't be there if it was just single animals. … an ecosystem function might be like herbivory, or bioerosion… calcification, the respiration/photosynthesis balance, that sort of thing. And I think some of those functions are ecosystem services as well, because I think ecosystem services are where things that ecosystem does provides benefit to people basically.” 1003

Again, these quotes revolve around the continued existence of self-sustaining systems of organisms, particularly with regard to how this impacts broad types of organism and the ways these types interact with one another. Both quotes stress qualities like biodiversity, and properties which emerge from the

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[135] It has been defined even more broadly in coral science as referring to ‘movement or storage of energy or material within an ecosystem’ (Bellwood et al., 2019).

interaction of single animals, i.e. they show a concern for something larger than individual organisms or species. Emphasis on stability, along with a range of other processes (bioerosion, herbivory, habitat formation) shows this is somewhat divorced from specific organisms or species but instead is a concern with a whole array of living entities and their patterns of interaction. This concern for larger scale systems and networks of interdependencies was made very explicit by some participants:

Quote 135

> 'So, coral reefs … you can make those, we call [it] network analysis, we have that beautiful figures with dots, each dot is a species, and there are connections between the dots right? So we have this very complex and colourful figure. And you have these that are central, central pieces of this puzzle. So, if you take off one of the central pieces, you can cause a very abrupt change in the structure of the network, right? So, with these approaches, **we can understand which ones are the most important species for maintaining this network resilience** in the face of human impacts or natural disturbance. **In coral reefs, you have so many important central species in this reef network**. **So [you] have these cleaners, mutualistic interactions are very important. So we have like the algae associated with corals, the cleaner fishes that are cleaning the larger fishes and they have also predators, some of the predators and herbivores.**' 1025

Comparisons to forests were also common in interviews[136]. One reason why is perhaps the importance in both cases of larger scale assemblages or networks of organisms. The participant in Quote 135 makes this clear: what they are interested in is resilience of an entire network of organisms, and their capacity to support one another, including through things such as mutualism, predation and herbivory.

This recalls the arguments around how to assess reef health earlier in this thesis (which focused on a whole range of different organisms in a nested family-resemblance scheme, allowing for variety between ecosystems in different contexts). When people intervene to modify components of the environment - such as algae or coral - or allow or facilitate the movement of several components of an ecosystem into cooler waters to avoid warming, they take a kind of holistic focus on the reef itself, prioritising certain perspectives on the ecosystem due to the value relations they have with it. Health metrics may aim to measure the key parts of a reef for supporting a wide range of

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[136] I plan to explore this in future work, along with comparisons to cities, which were also common.

organisms, such as the complexity and resilience of the carbonate structure of the reef, because these are important for the organisms which live in that environment (Lange, Perry and Alvarez-Filip, 2020). The point here is that coral science is also focused on the larger scale picture, the reef itself, as well as the human populations, non-human species, and individual organisms present. Sometimes work will be focused on modifications of ecosystems to save individuals or species, and sometimes the other way around. Practices and frameworks which focus solely on one element of this picture, such as individual humans, or individual species, at the expense of others, are likely to be criticised. So there are a whole set of possible beneficiaries of coral science here, and these will be impacted by scientific activities simultaneously. Where does this leave a socio-ecological account of coral science?

5. Putting it all together: the socio-ecology of coral science

> "It is as difficult to place the demarcation between the world and ourselves as it is to place the demarcation between the beach and the sea" – Merleau Ponty, via Gilliand (2021)

5.1 Niche construction in coral science

At the beginning of this chapter, I introduced the niche construction framework and highlighted some key questions niche construction theory poses for a given case of organism-environment interaction. Niche construction is the activity undertaken by a living system which is relevant to its environment, particularly in the context of goals such as survival, reproduction, fitness, cognition, and flourishing. Let's recap some of the questions I suggested niche construction theory can ask about scientific practice:

a. What is the focal entity? i.e., which entity's environment is shaped by the activity, and how do they benefit?
b. Who is the constructor? i.e., which entity is doing the activity?
c. What type of niche is being constructed? i.e., what are the goals or purposes the activity contributes to? This may include survival, reproduction, persistence, cognition, flourishing, and many others.

Having examined coral science from a socio-ecological perspective, i.e. in terms of how it is shaped by and shapes environments of different living systems, I now return to each of these questions to answer them explicitly. These questions offer a more ecological answer to the question of what constitutes good coral science, and what roles different forms of value play in this. First, the focal entity.

5.1.1 Focal entities

The focal entity of coral science is not one entity but a set of organisms, species, interrelations, and ecosystems. Whilst the coral scientist, other humans, and reef organisms all benefit from coral science as an activity, and whilst coral science aims to specifically benefit most of these entities, none is the sole focus. Activity which benefits just coral scientists is liable to criticism by other coral scientists, and activity which does not benefit them is unsustainable in most situations, given that coral science must also enable the continued existence of its practitioners (and itself as a set of practices). Given the strong affective links of coral scientists and reefs, and their desire to perpetuate them, activity which benefits reef organisms also benefits coral scientists too. Activity which only helps individual organisms and not higher-level entities like species and ecosystems as whole will also be liable to criticism. Interventions may harm individual entities, such as reef organisms in order to help protect others, such as reef species, ecosystems, or the human species. So there is no single entity which is the focus of coral science activity[137].

The activity I am discussing here includes run-of-the-mill observations of organisms within the lab or on the reef as well as more interventionist interactions which perturb the environment. Moving through environments and observing them might seem a strange form of niche construction, but is readily captured in the notion of niche choice, that is, an organism (coral scientist) modifying their relation to their environment, in this case by moving in and out of it. Such movement helps coral scientists understand the ecosystem, and to characterise it in terms related to the value of the entities present, for instance helping characterise the state of health of the ecosystem, which is conceived of in terms of the presence, absence, abundance and relation of certain resident species and organisms at the expense of others. More direct interventions also involve manipulation of niches of the conformational or constructional type, i.e.

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[137] This is, in reality, probably very typical of niche construction, given the ubiquity of symbiosis (Gilbert, Sapp and Tauber, 2012)

by modifying the phenotypes of organisms or modifying their environments in order to enable them to persist, or to enable other living systems to persist.

In short, coral science is aimed at furthering the survival, persistence, reproduction and flourishing of a set of organisms, species and ecosystems, both as individual entities and collective systems. They are caretakers not just for epistemic communities (Knorr-Cetina, 1999, p.38; Meyer and Molyneux-Hodgson, 2010, p.4) but multispecies epistemic communities, including not just the laboratory environment but aspects of the reef ecosystems they study and spend time in too. To do so involves modifying reef organisms themselves, their relations to their environments, and the environments they find themselves in. Which entities are focused on depends on several factors: it might include sets of organisms at higher risk, or sets of organisms which are particularly important for specific reasons (e.g. their ecological or economic impact), or organisms which garner attention due to things like their public popularity and charisma. Such considerations will not operate in isolation given the mutual interdependence of the living systems on a reef, and of the kinds of concerns just mentioned (e.g. ecological and economic value may often overlap).

Whilst niche construction theory is often applied to singular focal entities with other organisms involved in the construction (e.g. desert woodrats which can only digest creosote plants because of their gut microbes (Lala et al., forthcoming, chap.1)), it is less frequently applied to collective focal entities, where they occupy a fused or common niche (see Chiu and Gilbert (2015) for something like this). This raises a question here: is coral science aimed at a set of niches, or an overall collective niche for a heterogenous set of entities? It is unclear the extent to which niches can have multiple focal entities at once, or whether a singular system can occupy multiple niches. These problems recapitulate those found in individuating biological and ecological systems (Clarke, 2011; Dupre, 2001; Skillings, 2016). Further, the idea of ecosystems having niches (let alone constructing them) is a much more contentious one than the same (already somewhat contentious) idea for organisms or species. This raises further questions: how are niches individuated, and what does it take for multiple focal entities in multiple niches to be considered one focal entity in one niche?

Suffice to say here that coral scientists, well accustomed to dealing with lifeforms with messy boundaries, also operate in a way which deals with a plurality of niches at once, by aiming to construct the niches of multiple entities and kinds of entity at once, and being sensitive to activities which do not respect this balance. The question of how to grapple with these multi-entity problems is a tricky one, which I cover in more detail in the earlier chapters of this thesis (particularly those on baselines, health, and bioacoustics). This problem recapitulates some of core the problems of environmental ethics, namely which kind of entities are worthy of moral consideration (humans, living creatures, thinking/feeling creatures, ecosystems (Muraca, 2011)), as well as questions of politics ('what is to be done?' (Lenin, 1902) and who should decide this?) but also involves considerable contextual questions too, such as the historical range of an organism, the benefits it provides to other organisms, and many other economic, political and biological issues.

5.1.2 Constructors

The next question to ask here is who is doing the construction, i.e. who is modifying the environment? Reefs are populated and frequented by a range of niche constructing entities with different degrees of ability. Corals themselves, along with the algae that live within them, the other forms of algae which glue the reef together, the algae-eating fish which help maintain the delicate balance of coral and algae, and all the various other organisms involved in reefs, all construct and maintain the many overlapping niches involved in reefs (Sheppard et al., 2017). Lots of organisms help construct niches within one another and for one another, as well as for themselves. How this is characterised depends on where the boundaries of the systems in question are drawn. Coral and their endosymbiotic algae construct a niche together, as a holobiont, but also construct one for one another, and for external organisms. So there are reciprocal and networked constructive activities going on here.

I have focused on coral science, which is something done by coral scientists, and so it is also primarily their niche constructing power I have been concerned with. Coral scientists do work which ultimately enables or enacts the transformation and maintenance of environments in a way conducive to the persistence and flourishing of the set of living systems considered to represent a desirable, healthy or functioning ecosystem, and which factors in the value of the environment for other lifeforms. This is not to deny the constructive power of other living systems. Indeed, such powers are often explicitly invoked: it is partly because of the ability of coral to provide a surface for living on and in that it is the target of human efforts. Coral in turn allow for fish and algae to thrive in a way that further anchors the whole ecosystem, that is, they provide ecosystem functions[138].

So, not only do many living systems support one another here through constructive activity, coral scientists seek to use this web of interdependencies to prop up the entities they care for: be they organisms, species, or entire ecosystems. Interventions to remove or replace other entities, such as invasive or undesirable species, or organisms and ecosystems poorly adapted to projected future conditions, show how coral science is engaged in a kind of tussle between possible socio-ecologies (see Tsing (2015) for more on this, which she discusses using the concept of 'latent commons'). Anthropogenic and other factors push ecosystems in one direction, e.g. towards algae dominated reefs, or tropical arrangements in traditionally non-tropical areas, and coral scientists respond by categorising them in positive or negative terms, or studying ways to stabilise or dislodge them (Graham et al., 2013). Coral science involves multispecies niche construction both in terms of the niches it constructs, and the niche constructors themselves, then. Coral scientists study, protect, and set up networks of constructors which support one another, nudging societies and ecosystems in order to influence the competition between possible socio-ecologies, produced by the destabilising effects of human activity[139].

5.1.3 Kinds of niche

The final question is what kinds of niche are being constructed here, i.e., what are the purposes and goals underlying the modification of the environment? I listed several options earlier, which can run in parallel and overlap with one another: survival, development, fitness and reproduction, flourishing, cognition and knowing. Many of these goals are relevant to coral science, and they are

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[138] Specific measures exist to capture their ability to do this, such as the concept of rugosity (Knudby and Ledrew, 2007), or sets of metrics for measuring core ecosystem functions (Brandl et al., 2019). I hope to look in more detail at these in future work.

[139] Of course, not all changes will be produced by human activity, but may still be involved in the kind of socio-ecological tussling mentioned. For more on this, see Sapp, (1999).

intertwined. From the evidence I have presented here, it seems that coral scientists seek to aid the survival, development, and reproduction of specific reef organisms, the persistence of the overall ecosystem (and of dynamic ecosystem processes), and also the flourishing and thriving of themselves and other organisms (or indeed the ecosystem itself), on top of traditional scientific concerns such as understanding. This requires engaging in activity which simultaneously supports their own survival, but also enables the persistence of the ecosystems and organisms they care for, and allows scientists to cognitively engage with the reef system. Learning about reefs simply for the sake of knowing about them is a key part of the motivation of coral science activity, but blurs into efforts to help save the ecosystem, and both are an element of the flourishing of the coral scientist, and of the human species and the organisms and species associated with it.

In this sense, coral science is also about preserving and developing certain ways of life, those engaged with reefs in direct and indirect ways, such as appreciating, diving on, studying, being protected by, and eating from reefs. There is tension between different sets of practices and associated socio-ecologies – lifeforms and forms of life - which connects directly to the socio-ecological tugs-of-war playing out around the world[140]. The ways of life of the organisms on the reef (their life histories) are also bound up in these. Give that current human activity is incompatible with the continued existence of coral reefs in their current form, coral science finds itself the site of a negotiation between incompatible activities. Fossil fuel use, industrial fishing, pollution-generating endeavours, and various other practices all undermine the continued existence of reefs. This raises serious questions for the niche constructive activities of coral scientists: if something has to change, is it the reef ecosystem, us, or our relationship to it? In other words, do we modify the environment of this multi-entity coral system (niche construction), do we modify its relationship to the environment (niche choice), or do we modify the entity itself (niche conformance)? The same question can be posed from the perspective of any part of this multi-entity system, such as humans themselves, or individual reefs

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[140] As discussed in the introduction to this thesis, these combined socio-ecological arrangements can be phrased in many different ways: socio-ecological metabolic regimes (Landecker, 2013), sets of lifeforms and forms of life (Helmreich, 2009, p.6) or of entangled life histories (Rouse, 2023a), naturecultural arrangements (Haraway, 2003), or latent commons (Tsing, 2015).

species and organisms. A discussion on Coral-List (a mailing list for coral science) in April 2023 showed exactly these considerations, by arguing that coral scientists should focus on water restoration (i.e. modify the environment of the coral) rather than coral restoration (which treats them as primarily part of *our* environment)[141].

Which of these options are pursued depends on a variety of factors, such as the funding landscape of coral science, the predilections of coral scientists and their sense of the possible courses of action in the future. If neoliberalism in its current form seems inescapable, or funding is only provided for activities compatible with it, modifications of the biology of coral or other organisms may be the favoured pathway, as is being done in efforts to produce heat tolerant coral. This amounts to a modification of the fundamental niche of coral organisms in a way which brings them into line with the realised niche of humans, i.e. to the production of coral organisms compatible with modern day human behaviour. Similarly, geoengineering modifies the realised niche of corals in a way which doesn't disrupt the realised niche of humans, so as to make them compatible once more (but also alters the environment in various other ways). Modifying our behaviour so as to reduce anthropogenic stressors involves changing the realised niche of humans to make it compatible with coral organisms. So the tensions between the continued co-existence of reefs and humans always have both social and ecological dimensions, but changes may be more drastic in either dimension depending on the situation.

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[141] This was triggered by quoting and discussing another email from a previous exchange:

> " 'Everyone is focusing on restoration but corals will never thrive in polluted water'
> This stood out to me... The coral isn't the problem. It is the water. We should be working on *water* restoration. It feels very hopeless. What can I do as a young scientist? "

They got this response from another member:

"It does seem hopeless at times, but I would just encourage you as a young scientist not to give up and perhaps more importantly, not to lose sight of this revelation. What has to change is not only how we steward our waters, but how we interact with the entirety of the natural world. the task before you and others of your generation is no less than to change the fundamental way we view our relationship with nature. If you follow the coral sciences, the trend is clear and has been for decades. so, if you really want to take on this challenge you will have to help point humanity in the right direction by becoming an advocate for building new and fundamentally different societies based on sustainability in balance with nature rather than unfettered growth and consumption. My advice to you would be to stay in the coral sciences and help shift the focus from providing triage and treating symptom after symptom of a collapsing ecosystem and on to the need for directly confronting and effectively addressing causation" (Coral-List, 2023a)

These are not mutually exclusive pathways. All of these options are being pursued, and are compatible to some degree, with it being possible to modify the fundamental and realised niches of coral, and the realised niche of humans, simultaneously, and potentially in synergistic ways, such as buying time through modification of coral biology, in order to allow human behaviour to change. Through these decisions, anticipations about the future of human social systems, and the hopes and expectations of those funding and engaged in coral science, are inscribed in the coral ecosystems themselves. In the same way that evolutionary processes can be thought of as trying to predict the future environments of organisms (Lala et al., forthcoming; Odling-Smee and Laland, 2011, p.224), so coral science can be seen as doing so for the combined human-coral niche. Those who take climate change to be unstoppable may advocate for modification of the biology of reef organisms in order to help them weather the continued onslaught of human activity. The less fatalistic might try to protect them as they are, hoping to modify human behaviour beforehand. Disagreements in coral science track these kinds of views about likely future socio-ecological conditions (Braverman, 2018). These activities may be mixed and matched in ways that try to slow the destruction of the combined human-coral niche, but all will involve alteration of some feature of the overall socio-ecological system.

5.1.4 Stretching the niche concept

There is also sometimes scepticism about the utility of niche construction theory, both within ecology and especially when applied to other areas, such as I have done here. For those sceptical, I hope it is enough to say that it is primarily *socio-ecological construction* which is important here, and so the picture I have articulated is also compatible with related frameworks, such as ecological engineering (Jones, Lawton and Shachak, 1997), which comes with less evolutionary baggage. It is important to note though that there are explicit evolutionary dimensions to socio-ecological processes (Rouse, 2023a), including the ones I have discussed here. The activities organisms engage in, and the modifications they make to their environment, are shared and inherited and so persist in many cases beyond simply influencing one organism within their own lifespan. I think there are benefits to using niche construction theory in the way I have here, and to exploring what messier, more symbiotic and more relational accounts of science and organism-environment interactions look like.

5.2 The big picture: coral science as multispecies niche construction

The net result here is that coral science, on a socio-ecological account, is aimed at the modification of the niche a variety of different entities (and kinds of entities): people (and groups of people[142]), reef organisms, humans, other species, and ecosystem level associations of such things. Note that it is not simply just supporting the survival of some entities, but also the web of practices and associations it finds itself in. So when supporting coral scientists, this involves supporting the forms of life of the scientists (lab work, diving, meetings, emails, conferences), the laboratories themselves, larger networks of scientists, specific ways of doing science, larger institutes and collaborations they are embedded in, and a whole set of practices associated with these. The same might be said in a more directly ecological sense of specific lifeforms, namely that they are valued in part because of the ways they relate to the wider system they are a part of. Coral are one of the important and charismatic niche constructors in this system, and so are the subject of study and intervention in so far as they support the activities of a range of other organisms, human and non-human.

A socio-ecological perspective on coral science offers a way of understanding what it does do and should do in the minds of its practitioners. This offers an updated and situated answer to the classical descriptive and normative questions of philosophy of science. A fairly classic take on the aims of science is provided by Karl Popper: “clearly, different scientists have different aims and science itself (whatever that may mean) has no aims” but that broadly “it is the aim of science to find satisfactory explanations, of whatever strikes us as being in need of explanation” (Popper, 1972, chap.5). Here there is space for a variety of aims, and value of various sorts. Interests of individual scientists matter on Popper’s view, both in personal and impersonal senses, but the ecological dimension of science is absent.

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[142] It is worth noting that different groups of people will also be impacted differently by coral science, depending on their exposure to and dependence on reef systems. Whilst this is important, I do not go into it much here.

Angela Potochnik has built on this ‘satisfactory-explanation’ oriented view, and offers a useful summary on the overall aims of science: 'Yet there is an overarching theme that unifies those aims. All the aims of science further cognition or action; indeed, they further human cognition or action, as a science by and for human beings should.' (Potochnik, 2015, p.78). Here, human action takes a role alongside human cognition, something left implicit in Popper. Dupre (1993) makes a similar suggestion, but with an even more explicit ecological dimension, arguing that science can be seen more broadly as a set of heterogenous investigative practices and that the best way to evaluate the quality of such practices is through their contribution to flourishing: 'Science is a human product … like other human products, the only way it can ultimately be evaluated is in terms of whether it contributes to the thriving of the sentient beings in this universe’ (Dupré, 1993, p.264). The overall theme of these views on the aims of science is one of a practice which is deeply wedded to our need to navigate, manipulate, and understand the universe, i.e. scientific knowledge is impure, in that understanding and intervention are hard to separate in practice (Leonelli, 2009). Such a view is supported and expanded by the ecological dimensions of science I have explored here.

The account I have offered presents a slight twist on this, namely that it emphasises that science – at least in contexts like coral science - is a product of the interaction of humans and other lifeforms (including living systems at other scales), and that it can be evaluated in terms of its contribution to the flourishing or thriving of living systems, sentient or not[143]. Likewise, society is also a product of the interaction of humans and other organisms, and our realised ecological niches are propped up and held open by a range of other organisms (Rouse, 2023a). It is unsurprising then that coral science should be aimed at the perpetuation and thriving of a range of entities all at once, i.e. at the kind of multispecies flourishing championed by Donna Haraway (Haraway, 2016). This offers an answer to the question of what coral science is: a kind of conceptually-mediated constructive activity aimed at a set of living systems associated with coral reefs; and what good coral science is: the construction and maintenance of a specific range of niches associated with coral reefs, including humans and

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[143] Exactly which living systems are included in this evaluation depends on how they are valued, something covered in the chapters on baselines and health.

non-humans, in a way which responds positively to the threats they face (in order to protect valued elements of this system)[144]. These considerations include both biological systems and the social practices they are engaged in (Rouse, 2023a). Good science, detectable by being conducive to the kind of virtues discussed by Dupre and many others – e.g. sensitivity to empirical fact, coherence with other knowledge, predictive power, intelligibility (Dupré, 1993; de Regt, 2020; Potochnik, 2017) - is also detectable in an ecological sense by being conducive to the kinds of virtues associated with healthy ecosystems (which are discussed in chapter two).

Science, as always, is driven by many values, but in this picture, a key part of this is the value relations between the living systems involved in and impacted by the scientific process. Threats to the existence of these systems cause the proximal aims of coral scientists to shift, and different forms of value to be prioritised. Understanding the web of value relations tying reefs, humans and other living systems together is important if we are to understand what it is that coral science is doing, and what the futures of reefs and humans are to look like.

5.3 Ecological values in science

But where does truth sit in this picture? Isn't science traditionally articulated in terms of epistemic aims, that is, in searching for and discovering truth or knowledge? (Elliott, 2022). Whilst such aims are stressed in traditional accounts of science, the intertwining of such aims with personal and non-epistemic ones has been noted in socially-oriented studies of science (Hangel and Schmidt-Pfister, 2017; Potochnik, 2015). In a famous sociological study of science, Latour and Woolgar show that policy, evidence, and careers - i.e. public, epistemic, and personal factors – are interspersed with one another in discussions of the drivers of scientific activity (Latour and Woolgar, 1986, p.192). In socio-ecological studies of science, this theme is further exacerbated. Truth matters to scientists, but for a range of reasons (Potochnik, 2015). The discovery of truth, and contribution to understanding the universe, is an

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[144] In niche construction terms this could either be counteractive construction (i.e. mitigating some specific environmental change) or inceptive niche construction (introducing some change into the environment to benefit the focal entity). See more on this in Odling-Smee, Laland and Feldman (2003, p.45).

important part of the self-professed aims of scientists (Hangel and Schmidt-Pfister, 2017). But this process is also a personal one, a part of the niche of the scientist themselves, as an entity interested in the discovery of new things about the universe[145]. Curiosity is a personal value as well as an epistemic one, one related to the flourishing of coral scientists and the social practices they engage in. Furthermore, discovery of truths for their own sake – how epistemic value is traditionally conceived - may take a back seat when the survival of some part of the multispecies nexus involved in coral science is at stake, just as truth may take a back seat when producing other epistemic goods such as understanding or intelligibility (Potochnik, 2015; Currie, 2020). Truth is of course important in sustaining the various entities involved in coral science, by allowing scientists to continue to construct niches under changing conditions, but it may not always have a primary role. Just as certain elements of nature are idealised in scientific settings in order to meet both epistemic and social aims, so they may be idealised in order to produce certain ecological conditions, i.e. to contribute to the survival and flourishing of various types of living system. Ecological baselines, which formed the starting point of this thesis, are the quintessential example of this ecologically-oriented idealisation (Jones, 2021).

This recognition of the importance of producing multispecies flourishing, rather than discovering truths as an isolated goal, is visible elsewhere. Some scientists have suggested a moratorium on climate research – i.e. stopping doing what is regarded by many as the chief activity of science (research) – because of the threat of the radical transformation of the system they study (the climate) (Glavovic, Smith and White, 2021). The same worry is present in coral reef research, and is sometimes articulated through the phrase ‘documenting the decline’, mentioned earlier and outlined here:

Quote 136

> ‘I just simply don't think that it's for lack of information, and if we just find one more fish who behaves differently because of climate change, that'll be the thing, that'll be the straw that breaks the camel's back, and all of a sudden, we stop emitting carbon. So I think that **there's a lot of interesting questions that**

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[145] ‘[t]he scientist does not study nature because it is useful to do so. He studies it because he takes pleasure in it, and he takes pleasure in it because it is beautiful. I am not speaking, of course, of the beauty which strikes the senses […] What I mean is that more intimate beauty which comes from the harmonious order of its parts, and which pure intelligence can grasp.’ (Poincaré, 2003, p.22) (I would modify this to say that they do not study nature *just* because it is useful to do so).

> **we can explore out of general curiosity of understanding our systems and understanding how they will look in the future, but I think the most pressing question above all else should be a solution to the climate emergency**.' 1007

Here, the emphasis is on the pressing questions of how these systems will survive in the future, not simply epistemic considerations of how they operate. Contributing to a greater understanding of these systems in a way divorced from the struggle to keep them in existence may even be seen as bad, or at the very least a waste of time, in that it does not necessarily help sustain the existence of the ecological entities valued by coral scientists. This has been termed 'documenting the decline', a pejorative term for a kind of transfixion on doing largely epiphenomenal science whilst the object of study slips out of existence. This was articulated at length by one interviewee:

Quote 137

> **"**And, you know, academia still has the same set of incentives that it's had forever, um, publish papers, get grants, publish or perish, you know, this kind of thing. There is a drive to change that, but honestly, it still hasn't changed. And so those are the levers that push you in academia, where we have these giant problems over here, where those levers don't matter**. And so then how as a young person am I supposed to get satisfaction about being in academia and doing this you know, treadmill publish or perish thing, when what I really want to help with are these big questions,** and that's such a hard... I get that every time I give a talk now, and I don't have an answer, but it's real." 1026

Quote 138

> "And I had an opportunity to really pull back and think openly about science in a way that I hadn't in a while. And I really came to terms with, what's happening to coral reefs. And I had a crisis. Honestly, I had a crisis of confidence about the value of science, the value of basic research. And you know, prior to that, I think I was just, you know, I... you cope, you cope with things, you cope with denial, you cope with ignoring. And that year I just couldn't... I... the blinders came off... my dear friend Ruth Gates who passed away, she was still alive at that point and was really starting to get a lot of traction in the sort of public eye about corals and saving corals and working on that. And, you know, anyway, so I really was thinking, what am I doing? **You know, who cares about basic research, when you're not even going to have a research animal left in 25 years? What is the point?** And it was very hard for me, because, here I have a lab full of graduate students who I've sold a bill of goods to, you know, basic research is good, incremental building bricks in the wall, this is all good, you know, we're moving science forward. And suddenly, I really wondered if it was valuable. I just didn't really know. And so I've come back three years later, right, pandemic, and all. I've softened my approach to that. But I still believe that science is not serving... **the basic academic research is not serving corals as well as it could and should.** And part of it is my age, right? I'm older, I'm sort of beyond the peak of my career. So I'm seeing the whole arc of things. And, you know, the way in which academia is done is this slow incremental

> approach where you publish things. Anyway, so Ruth's approach was, we don't have time for that, we have to really push, and do things differently." 1026[146]

Here, we see again that more epistemic or self-oriented actions, such as curiosity-driven research and publication, can take a back seat when the systems being studied are themselves under threat. This is part of the impetus to greater conservation and restoration work by scientists, and the development of new tools to aid these tasks. It also intersects with the personal expectations people have around the political and economic conditions of the future. If the kind of economic system we currently find ourselves in is to continue to exist – if, as is often said, it is easier to imagine the end of the world than the end of capitalism[147] – then scientists will be moved to construct niches which fit within a future capitalist socio-ecology, e.g. by heavily altering the biology of corals to make their fundamental niches fit with our realised ones. If the outlook is less gloomy, smaller biological modifications may be appropriate, or none if conservation measures can be used to reduce the disturbances faced by reefs. So the appropriate aims for coral scientists to take depend on the current and future socio-ecological context that scientists and reefs find themselves in. In times of (desirable) ecological stability, scientists only have to worry about perpetuating the social practices associated with coral reef science. Once the ecology underlying their scientific practices is threatened, it becomes imperative to protect and salvage that environment.

The frustration articulated in the previous quotes is that coral scientists are unable to easily shift their behaviour to match the aims of coral science which are becoming more important, i.e. they are unable to focus as strongly as they would like on simply helping reefs survive, be that through modifying the ecosystem itself or by preventing its environment from changing. The incentive structure of academia poses barriers to this by forcing them to also concentrate on their own niches (i.e. their ability to continue existing, both as an individual and as a scientist) and those of other entities such as the organisation they find themselves in. There is also frustration at being unable to make changes at the scale of global CO_2 emissions, which is where one of the most pressing threats to coral reef organisms lies.

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[146] This quote refers to Ruth Gates, a high profile coral scientist who died in 2018 (Yong, 2018).

[147] This is attributed to Slavoj Zizek and Frederic Jameson (Fisher, 2009)

The key point here is that coral science sits at the interface of several kinds of living systems, and good coral science strikes a balance between meeting their needs. Epistemic value and curiosity fit into this picture in so far as they help scientists meet these, and can take a front seat itself when there are fewer threats to the continued existence of this multispecies system. So, for example, when reefs were not considered as seriously threatened, such as in the 1980s, the normal publication-oriented and non-translational research framework was less problematic. The shift to a more interventionist mode of operation, framed often in medical terms (Ankeny and Leonelli, 2019), can be understood as a reorientation to protect the elements of coral science which are threatened, namely the ecosystems being studied. In this example by adopting the trappings of an area of science which is explicitly and frequently about producing healthy and thriving objects of study, i.e. medicine (Ankeny and Leonelli, 2019).

A socio-ecological view of science suggests there is a web of entities, interdependent on one another, which can be studied, protected, nudged, and modified in order to help maintain the whole system, and allow the socio-ecological practices of coral science and coral reefs to continue. When corals are endangered, coral science is too, as are the livelihoods of various human populations and other organisms tied into the flourishing of the overall system, be that through protein, tourism, wave protection, or coral science. Coral scientists have the job of maintaining much of this in the face of changing ecological conditions and largely static (but unsustainable) socio-economic ones. Scientists are not just caretakers of labs (Knorr-Cetina, 1999), or housekeepers of epistemic communities (Meyer and Molyneux-Hodgson, 2010), but multispecies niche constructors too, maintaining the whole socio-ecological structure associated with their scientific practices. On this view, there are an extra set of values which drive and shape coral science, as scientists have a strong motivation to maintain certain ecological arrangements and entities within them. This offers a shift from thinking about science as about obtaining knowledge (or knowledge relevant to social contexts) to thinking about science as sustaining a diverse set of living systems, i.e. as a fundamentally socio-ecological enterprise[148].

This builds on an insight offered by Rouse (2015, 2023b): that science is a hard won set of activities which are not guaranteed to exist, but which depend on the existence of a set of environments and social practices in order to continue operating. This can be fleshed out here. Science, as conceptually mediated niche construction, is a special form of the activity of living systems. The kind of curiosity-driven fundamental science we so often associate with science is most feasible in circumstances where the needs of the living systems involved in those activities are largely being met. This makes it possible for more exploratory and possibility-oriented scientific activity to take place. When features of this system are threatened, the scientific process may shift to direct attention and effort at protecting the relevant entities (this is not done by an invisible hand or some inherent self-correcting process, but by conscious decisions and hard work). At the extreme, when the livelihoods of scientists or their study systems are threatened, or the social practices and environments of science disrupted, scientific activity can no longer continue, or continues in a much-reduced fashion. Scientific activity, especially of the ground-breaking and exploratory kind, requires certain socio-ecological conditions to take place, and if these do not exist, it may cease to exist entirely[149],[150].

6. Conclusion

Whilst epistemic and social accounts of science have sought to understand how it is shaped and shapes belief, knowledge formation, and society, I have added an ecological edge to this here. Science is a process which fundamentally involves rearranging or maintaining parts of the world, and so it can be

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[148] With thanks to Rose Trappes for pushing me to highlight this here.

[149] I intend to write elsewhere about these processes which I have been calling ‘epistemic degradation’ or ‘global flummoxing’, whereby changes in our environment make the world harder to understand. Many examples illustrate this: space junk occluding and confusing our ability to see into space (and of other organisms to navigate) (Lawrence et al., 2022), and the changing chemical, auditory and visual properties of the ocean preventing navigation and communication by animals (Yong, 2022) provide just two stark cases. This raises an alternative version of the bottleneck hypothesis (itself an answer to the Fermi paradox about the seeming absence of intelligent alien life): that intelligent life tends not to kill itself, but to make itself unintelligent (a kind of cosmic lobotomy hypothesis), perhaps being unable to keep up with the changes it makes to its own environment.

[150] In a broader sense, much of the history of science demonstrates the environmental dependence of both good science, and of exploratory science. This sometimes occurs in dramatic and troubling episodes, such as in the case of Lysenkoism.

understood from the perspective of how it is shaped by and shapes the material and biological conditions it exists in. This ecological analysis complements social analyses of science. Theories and concepts from ecology and socio-ecology can therefore be useful in studies of science itself. More specifically, theories around organism-environment interactions, notably niche construction theory and ecological value frameworks, can be used to better understand scientific practice. In the case I explored here this is much more obvious: the value of various features of coral ecosystems drives the conceptual and constructive activities of coral scientists. On this view, coral science is aimed at producing flourishing in a set of living systems, with epistemic considerations weaved into this, but not the primary component. More purely epistemic activity takes a front seat only when these living systems are not under serious threat. Exactly which systems fall under the purview of constructive activity in science depends on how they are valued. This helps flesh out the non-arbitrary origins of the values which inform baselines and health assessments of reefs, where baselines involve socio-ecologically driven idealisations which are designed to ensure the right valuable entities are preserved and prioritised in scientific activity.

Thesis Conclusion

At the end of June 2022, during a research visit to the Konrad Lorenz Institute in Austria, we took a trip to the monastery in Brno where Gregor Mendel lived, as part of an event to mark his two hundredth birthday. Whilst there we learned about what, in the context of this thesis, I would call the socio-ecology of Mendel’s work (or, in more conventional terms, his research environment). The monastery supported Mendel’s needs, providing him shelter, food and the resources for his work, and the greenhouse played a similar role for the pea plants he famously experimented on (mediated, of course, by the kind of cross-species care touched on in chapter four). Similar examples can be found in sea-adjacent marine laboratories, buildings where pipes often bring local seawater in and pump it around the building to the various marine occupants. In both cases an interweaving of the niches of scientists and study organisms occurs. Not just conceptually, but physically and deliberately, in the planning and design of the environments. The same is true of scuba divers, or operators of remote vehicles in the sea, which extend the environment of the human observer and experimenter so as to overlap it with the environment of the relevant non-humans. It is at these junctures where many of the epistemic interactions I have been tracing here take place. These scientific interactions are also social and ecological ones, and disruptions to the socio-ecology underlying them changes how they take place.

In coral science, individuals build up rich histories of interactions with reef environments and find themselves enmeshed in webs of value with their objects of study, influencing the work they do and the activities this entails. This web of value partially determines how these environments are characterised – for example via the baselining process - in a way which makes science relevant to the diverse lifeforms and forms of life present. Through a web of simultaneously intrinsic and instrumental value relations, which incorporate the perspectives of non-human organisms and the value of environments from these perspectives, coral scientists act to maintain and reshape the reef system in order to perpetuate the flourishing of specific multispecies arrangements. Epistemic considerations are weaved into this, but are not the primary component. More purely epistemic activity takes a front seat only when these living systems are not under serious threat. Exactly which systems fall under the purview of constructive activity in science depends on how they are valued.

Recognising the socio-ecological dimensions of science adds extra tools into the arsenal of those interested in understanding scientific processes. On top of epistemic and social considerations, it is also important to think about the living environment of the scientist. Socio-ecological considerations can – just like epistemic ones – drive processes like idealisation, or be factored into the question of what counts as good science. On top of traditional criteria for assessing science – things like reproducibility, accuracy, sensitivity to a broad range of evidence - can be laid socio-ecological questions, such as how the scientific activity shapes the relevant environment. In terms of coral science, good coral science aims at producing healthy reefs. This is why baselines cannot be determined simply by history, because they encode within them an understanding of what makes for a desirable socio-ecology, which itself depends on which stakeholders are being considered and the value relations they exist in. Anxiety over appropriate baselines is anxiety over which sorts of multispecies flourishing scientists ought to be promoting, a question which strikes to the heart of the scientific endeavour, and cannot be settled simply by studying the environment itself, but requires an understanding of the lifeforms, forms of life and value relations associated with it too.

Coral science, I have argued throughout this thesis, is a site where the fates of reefs, scientists, and a range of other entities come together. It is aimed fundamentally not simply at discovering truth, but at perpetuating a kind of shared niche between a great many organisms and living systems. Science, on this account, strikes a balance between survival and curiosity, overcoming problems in the immediate environment and discovering new problems in the mediate one. Environments are epistemic, and laboratories ecological. The values which run through science are much like those which run through everyday life: a mixture of personal, social and epistemic concerns, involving the ecological, economic and affective. Values in science do not just appear as products at the end of processes, nor as fixed forms, but as relations between entities, strung together, sometimes in longstanding ecological arrangements and sometimes brand-new ones.

Coral science is the process of understanding and supporting these relations from within them. It is an activity primarily aimed at sustaining a set of living systems and their ways of life, which is responsive to the socio-ecological context it is embedded in, and in which different value relations between organisms and environments will take priority depending on this context. It is for this reason that coral science has shifted towards more interventionist practices recently, and is also why some practices are contentious, such as in debates over appropriate metrics for measuring reef health, what baselines should look like for reefs, and how to intervene to best sustain reef systems. Each of these questions has implications for the kind of socio-ecological systems being produced by coral scientific activity.

Values in a socio-ecology of science: intrinsic, instrumental, epistemic

The picture of coral science I have offered throughout this thesis is one of a multispecies tapestry, where threats to one part necessitate a shift from curiosity-oriented epistemic concerns to survival-oriented practical ones. When the socio-ecological context shifts, so do the values chiefly driving coral science. But how does this fit with the literature on values in science, and values in ecosystems?

In the last chapter, I examined the niches involved in coral science. From this perspective, scientific activity acts (and should act) in the interests of a mixture of humans, reef organisms, species, and ecosystems, facilitating both their survival and flourishing. The simultaneous employment of intrinsic and instrumental modes of valuation over a range of different living systems, including valuation which may be indexed to the perceptive of other organisms, makes for a complicated mixture of beneficiaries of coral science as a practice, and one which may shift with context[151]. Here, there are anthropocentric, biocentric and ecocentric conceptions of value all operating simultaneously. These forms of value drive and shape coral science activity in the same way that values have been shown to in other areas of science. So in the same way that inflation rates are designed to be relevant to the lives of certain groups of people (Dupré, 2007), the characterisation of reef states depends on how they provide value to humans, other species, and the ecosystem itself (Jones, 2021). When different forms of value take priority, they will necessitate and facilitate different kinds of change, and different scientific activities. For example, treating coral reefs as primarily service providers will allow for change within them in order to maintain services – such as change in the types of organism present - and will characterise such change in a positive light, as long as they preserve or enhance services.

We can make sense of coral science activity as driven in part by the instrumental and intrinsic value of the systems being studied, and also through other concepts which pick out valuable features of the environment such as ecosystem services and functions. These show coral science as a process which intervenes in the world to produce certain outcomes, including arrangements of organisms and abiotic features, in accordance with the value

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[151] The 'trumping quality' definition of intrinsic value, i.e. that it is often considered infinite in magnitude (O'Neill, 1992), has interesting connections with decisions about which elements of a system are modified in restoration attempts. On this view, intrinsic value is a byword for entities we prioritise to the point that we would rather modify their surroundings to sustain them than vice versa.

these features have for the relevant actors. These distinctions (intrinsic/instrumental, service/function) are useful for understanding this process, but can also be nuanced further by considering them as modes of valuation rather than fixed concepts. A similar set of distinctions can be found in conversations about values in science, notably between epistemic and non-epistemic values. Epistemic values are those related to searching for and discovering truth (Elliott, 2022). These are the traditionally-vaunted goals of science. Recent developments point to many non-epistemic goals of science, such as those related to ethics, aesthetics, politics, and other considerations (Rooney, 1992; Lusk and Elliott, 2022; Ivanova, 2017). I have argued here that the state of the ecosystem a scientist finds themself involved in, be that a coral reef, a laboratory, or something in between, also drives and shapes their work. So it is important to consider ecological as well as social values in science. But where does the epistemic fit here?

In line with challenges made to the epistemic/non-epistemic distinction elsewhere, the picture I paint here treats these as deeply interconnected categories. Truth matters to scientists, but for a range of reasons (Potochnik, 2015). The discovery of truth, and contribution to understanding the universe, is an important part of the self-professed aims of scientists (Hangel and Schmidt-Pfister, 2017). But this process is also a personal one, a part of the niche of the scientist themselves, as an entity interested in the discovery of new things about the universe. Curiosity is a personal value as well as an epistemic one, one related to the flourishing of coral scientists and to the social practices they engage in.

Beyond this, the discovery of truth for its own sake – the traditional formulation of epistemic goals – is bound up in the other goals of the scientist. Curiosity-driven and not obviously immediately useful work may take a back seat when some part of the reef-scientist system is threatened. This is not to deny the importance of true theories in this process, but to argue that the gap between true theories and successful practices is larger than it might initially seem. Truth allows scientists to navigate the world, and so to sustain the socio-ecological systems they care about, but it may not always have a primary role. Scientists may idealise for a variety of reasons: producing understanding, producing certain environmental states, meeting socio-ecological aims. This is also not to deny the distinction between epistemic and non-epistemic aims, but to bind them together and to the lifeforms and forms of life they emerge from. Science, I have argued, is aimed at producing the flourishing of a set of living systems, and this produces room for different practices to be considered successful, depending on the criteria employed to assess them. Different baselines – although not just any baselines - may be successfully employed to assess the same ecological state. In such cases, epistemic values such as accuracy and reliability will matter, but they are joined up with a concern for producing the right kinds of changes within the social and material environment of those who interact with reefs. By recognising that science is a socio-ecological process, it is possible to explore in more detail the forces shaping scientific practices and the ecosystems they focus on.

Relational values in science

This picture of a mesh of living systems – a field of life - working partially autonomously and partially in concert with one another, and maintained and changed by the activity of coral scientists, stretches the concepts I originally sought to apply here. Niches become a less singular and discrete matter and more of a continuous and inter-dependent one. The value frameworks I have used so far similarly tend to treat organisms and species as distinct entities with clear boundaries, rather than as precipitates out of interactions between a variety of differently-delineable living systems. Once things are seen this way, the dichotomies of intrinsic/instrumental, non/epistemic and human/nature start to take on a more blurred (but still workable) sense.

By treating values in science as relational, a more dynamic approach to understanding them is possible. When ecosystems are at risk coral scientists may relate to them in ways which stress their uniqueness and non-substitutability. When organisms change context, say lionfish outside of their presumed normal habitats, they will be valued differently, for example becoming the subject of organised killing due to their invasive status and impact on the broader environment. Ecosystems which were seen as degraded can become objects of protection, for example previously coral-heavy reefs in the Caribbean becoming dominated by urchins, and now subject to efforts to prevent them from becoming more heavily algae-dominated. Alterations thought inconceivable, such as introductions of novel species into historically alien ecosystems, may become thinkable once those ecosystems are threatened, or in ecosystems such as the Biosphere 2 reef nestled in an artificial chamber in Arizona, where scientific aims can be pursued without fear of altering the other socio-ecological features of wild ecosystems. The status of any entity impacted by coral science will shift with socio-ecological context, and so will the kinds of values pursued by scientists, and relating scientists to their objects of study. Corals, and other parts of reef systems, can have epistemic, intrinsic, instrumental, function and service value simultaneously, and scientists may choose to act on some of these value relations at the expense of others. Coral scientists care about corals because of what corals do, how they feel about them, their unique features, their aesthetic significance, the web of symbioses they support, and because they are living creatures. Each of these (and many more) aspects may take priority at different times. The roles scientists, corals and other organisms play relative to one another shift, and the activities associated with coral science will shift with these.

This kind of multifactorial approach to values in science, and the importance of highlighting different contexts when examining the driving forces of science, comes together in the following quote:

Quote 139

> “[after being asked why they were interested in coral science at university]
>
> I think a few reasons. I probably could summarize them into: **it was fun and it felt really relevant and important**. So I find it more fun than some other stuff because they're **naturally very beautiful ecosystems to be in, to spend time in, to look at, to analyse**. … There's also the aspect that they're **fantastically complex ecosystems to try and understand, to work in, in terms of just being sort of overwhelmed by the diversity and the abundance of the animals there, … it sort of really hits you in the face**. And then also just the logistical difficulty of trying to work there, I think, is quite fun … you're getting battered by storms and having to work out how to get to remote islands and everything's under water and you're trying to hold your breath while you're doing all this stuff. …
>
> **And then in terms of the relevance, I felt quite attracted to working on something that's so globally discussed and globally relevant. People talk about coral reefs, I think rightly so, as being the poster child of environmental degradation**, and the sort of canary in the coal mine. That’s it really isn't it, when you talk about discussions of can we save the world, you know, is nature going to survive? **Can we coexist with this?** Are we going to lose all this fantastic biodiversity around the planet**? It really isn't long before coral reefs enter that conversation and they're usually the first biome that people talk about when they talk about biodiversity decline. And so having been driven from a very young age to work and be interested in**

> **protecting nature, I think it was perhaps slightly inevitable that at some point, I'd have my attention caught by reefs, because I think they are the pinnacle of that question, of that challenge**.” 1003

So coral science, as an activity, is shot through with a range of values which originate in the different sorts of relationships scientists have with the living systems involved: the personal enjoyment and satisfaction of being in and exploring the ecosystem; the value of the ecosystem as a unique living system, and as a system which scientists have strong affective connections with; the importance it has for the various living entities supporting and supported by it; the complexity and mystery of the system; the struggle to carve out a sustainable place for humans in the world and the reef at the forefront of that challenge. All of these considerations and more drive and shape coral science, and the importance placed on each will shift with the conditions the scientist and ecosystem find themselves in. This mixed up web of values, including the personal, the epistemic, the ecological and the economic, is seen across much of science (Hangel and Schmidt-Pfister, 2017). Affective value is regularly imparted by researchers on their objects of study, such as in the case of model organisms, which can come to define the identities of scientific communities (Ankeny and Leonelli, 2011, p.317). The threats to coral reefs make this particularly obvious here (see e.g. Gordon, Radford and Simpson (2019); Braverman (2016)). The weaving together of these forms of value does not threaten the status of science, but situates it as a set of practices deeply relevant to the lifeforms which practice and are influenced by it, and the forms of life in which it is embedded.

Relational value advocates sometimes move so far away from traditional conceptions of value to advocate a kind of eliminativism about the concept of value: “There are no such things as values. There are rather the various ways in which individuals, processes and places matter, our various modes of relating to them, and the various considerations that enter into our deliberations about action” (O'Neill et al., 2008, via Tadaki, Sinner and Chan, 2017). I agree with much of this: it is good to connect discussion about value to the specific context, and to explore differences within the category of value, as well as being specific about what is valuable, for who, and how (Norton and Sanbeg, 2020, p.4). But as I have shown, traditional value frameworks – such as intrinsic and instrumental value – can and do accommodate a wider range of nuance than might be expected, especially when treated relationally. These insights can be brought together without throwing out the concept of value entirely.

Relevance to other areas

But which other areas of science might these conclusions be relevant to? It is of course important to note that coral science is to a great degree publicly funded and not oriented towards producing private research, goods, or commodifiable results, unlike other areas of science (such as biotechnological ones) (Sunder Rajan, 2006; Helmreich, 2009, chap.3). As such, the relevance of some aspects of this thesis to more commercial areas of science may be limited.

That said, the issue of baselines is a widespread one which is becoming increasingly pertinent as humans are less able to take for granted the comparative stability of socio-ecological arrangements. There are already big questions in ocean temperature modelling about how to label events as ‘heatwaves’ given that temperatures are steadily rising, necessitating choices between having perpetual heatwaves or allowing for a shift in what counts as normal so that acute events can be better highlighted (Amaya et al., 2023). Other areas of science where study environments are changing can be expected to have similar debates, and the lessons of this thesis will be relevant there too: these are debates about how to best ensure the flourishing of a range of living systems, and so cannot be solved by only gathering data. They require consideration of the values and perspectives of the relevant lifeforms and forms of life.

More broadly, society is confronted with the problem of climate change, and so we can expect to see concern with the socio-ecological impacts of science - both in terms of incidental and deliberate impacts of scientific activity - being more closely considered. Areas of science where particular study organisms or ecosystems are disappearing, or where they are threatened, can expect to see shifts to adopt new repertoires (perhaps from other sciences which are perceived as being successful at intervening to produce certain socio-ecological outcomes, as with coral science borrowing from medicine), and a shift to activities typically not considered under the purview of normal science in that area, such as science communication, direct restoration, conservation work, monitoring, or increased interdisciplinarity[152]. This is not to say other sciences will necessarily copy the template of coral science: there are many ways these processes can play out, depending on the specificities of the science itself and the socio-ecological context it finds itself in. But shifts to new activities in response to socio-ecological context can still be expected.

This includes shifts to more explicitly political activity such as research moratoriums (Glavovic, Smith and White, 2021) or direct political action, with climate scientists well represented in climate protest movements in the UK, engaging in activities increasingly deemed criminal by the UK justice system (and not just because the UK justice system increasingly deems all kinds of activities criminal) (Cork, 2023). The expression by coral scientists of frustration with both scientific and political institutions, and criticisms along the lines of 'documenting the decline' is symptomatic of this. Other areas can be expected to respond similarly as the ecologies of different scientific activities come under direct threat and their practitioners struggle to address these threats through their existing professional activities. This is particularly the case given the failure of governments and private companies to take significant action to address climate change.

The acuteness of this problem in coral science means that more shifts in the activities associated with coral science can also be expected. These changes continue as I finish writing this thesis. A post on Coral-List (a mailing list for coral scientists) from 20th July 2023 stressed that anomalously high sea surface temperatures through spring and summer 2023 are a 'game changer for coral reefs and it is possibly a threat to our careers' (Coral-List, 2023b). Far from being callous or self-interested, these concerns stress that coral science takes place within a socio-ecological web, and once that web starts to unravel, so the scientific processes taking place can be expected to change. Some on Coral-List are arguing that coral science should be further transformed, with a greater emphasis on simply enabling coral to persist within indoor storage facilities, in the face of highly anomalous ocean temperatures in spring/summer 2023,

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[152] I have not discussed in this thesis the increasingly use of social science in many areas of marine science. This does however demonstrate the phenomenon I have discussed here, whereby scientists search for new repertoires to deal with crises which cannot be tackled through application of their traditional activities, in this case, seeking to tackle the human aspect of marine problems. With thanks to Anna Woodhead for raising this.

which threaten even very well-orchestrated restoration programmes (Coral-List, 2023c). The start of this process has been traced already by Samantha Muka in her book ‘Oceans Under Glass’ (Muka, 2023). Suffice to say that adoption of the repertoires of medical science in response to threats to reefs (Ankeny and Leonelli, 2019) is likely to be only one of many dramatic changes to the nature and operation of coral science in the coming years.

Last remarks and future avenues

There are many areas I did not have time to explore extensively in this thesis which have strong links to the topics here. Throughout animal studies there is lots of relevant work, especially relating to the role of care in science, which I intend to explore connections with in the future. I had originally intended for a chapter on some of the specific epistemic functions of coral reefs, however the rest of the thesis expanded sufficiently to preclude this. It will hopefully be the topic of a future postdoctoral project. There is a burgeoning literature on the ’blue economy’ which is very relevant to this work, particularly the nature of value in such movements. I had also hoped to dig deeper into the ecological factors which make coral reefs valuable, including the importance of their structural complexity in driving this (something called ‘rugosity’ in coral science). I intend to explore connections between this, ecological metabolism (another possible way of theorising across the natural-social divide (Landecker, 2013)) and parallels between corals, cities, and forests, in future work. Finally, I hope to explore further the roles played by baselines in coral science and other areas, given the important and under-theorised role they play in science, especially in a world changing (in some respects, although unfortunately not in others) as rapidly as ours now is.

There are also questions I have left unanswered here: for example, the notion that coral science is aimed at the flourishing or thriving of a set of living systems is a vague one. Which systems should be included and why? I did not and cannot provide an answer to this. Instead, I have shown that there is not an answer that can be given simply on the basis of facts about the system. There needs to be space for debate, deliberation, and multiple reasonable answers, if we are to avoid the traps of socio-biology and other forms of biological determinism. I have not set out here to say what a baseline should include, or the kind of flourishing that scientists should aim for, but to sketch how this process operates, how it fits with the practices of coral science, and how different forms of value interact with one another and these processes. I have provided an indication of how baselines may vary, how health judgements depend on the level of abstraction of an ecosystem but also leave space for multiple versions of health, how intrinsic and instrumental value pick out a variety of overlapping features of ecosystems, how these features may be valuable from non-human perspectives, and how these various forms of value help ensure the socio-ecological relevance and desirability of the work of coral scientists. These do not pre-determine an answer to the question of what makes for a healthy reef, or good science, but help provide a clearer path to deliberating on this.

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Appendix

Appendix 1: Interview protocol

Below is the interview protocol used for most of the interviews (this changed slightly throughout the project, see the methodology section for more on this).

Understanding Coral Value – Interview Protocol v1.3

Start: Confirm they have read and signed the consent form, and that I am recording the interview.

Specific topics of interest:

[space for specific topics relevant to individual participant which I noted could be of interest to cover]

General questions:

- How did you end up studying corals?
    - How did you get into marine biology more broadly? (if not covered)
- What aspects of coral reefs do you study? What led you to work on those aspects?
- What kinds of coral reefs do you study? (is there a specific reef, area or reef organism you study?)
    - What interests you about these?
- What are the biggest changes you've seen happening to reefs in your career?
- Is there anything you wish more people knew about coral reefs?

More specific questions:

- What tools or systems do you use to understand coral? Do you use any models, or model organisms? (digital/biological)?
- What are the biggest scientific insights to come out of studying corals?
- What are the key functions of coral systems?
- Do you use the term ecosystem services in your work, and why?
    - Are you aware of criticisms of the notion? Do you think criticisms are justified or not?
    - What, if any, is the difference between functions and services?
- What does a healthy coral reef look like? (does everyone agree?)
    - If time: why are reefs so important as marine environments?

- Which aspects of coral reefs would be hardest to replace if they suddenly disappeared? What would be the biggest changes to our lives?

- Do you participate in any restoration projects?
    - Follow-up about views on restoration

Closing questions:

- Can you think of any moment where learning something about coral changed your appreciation of them or of the living world generally?

- Do you have any questions for me, or anything you'd like to add?

Closing remarks

Thanks, and reminder about choosing to change data/anonymity preferences/withdraw.

If extra time:

- Have your perceptions of the aesthetics of coral changed since you have been working on them?
- Do you dive recreationally?

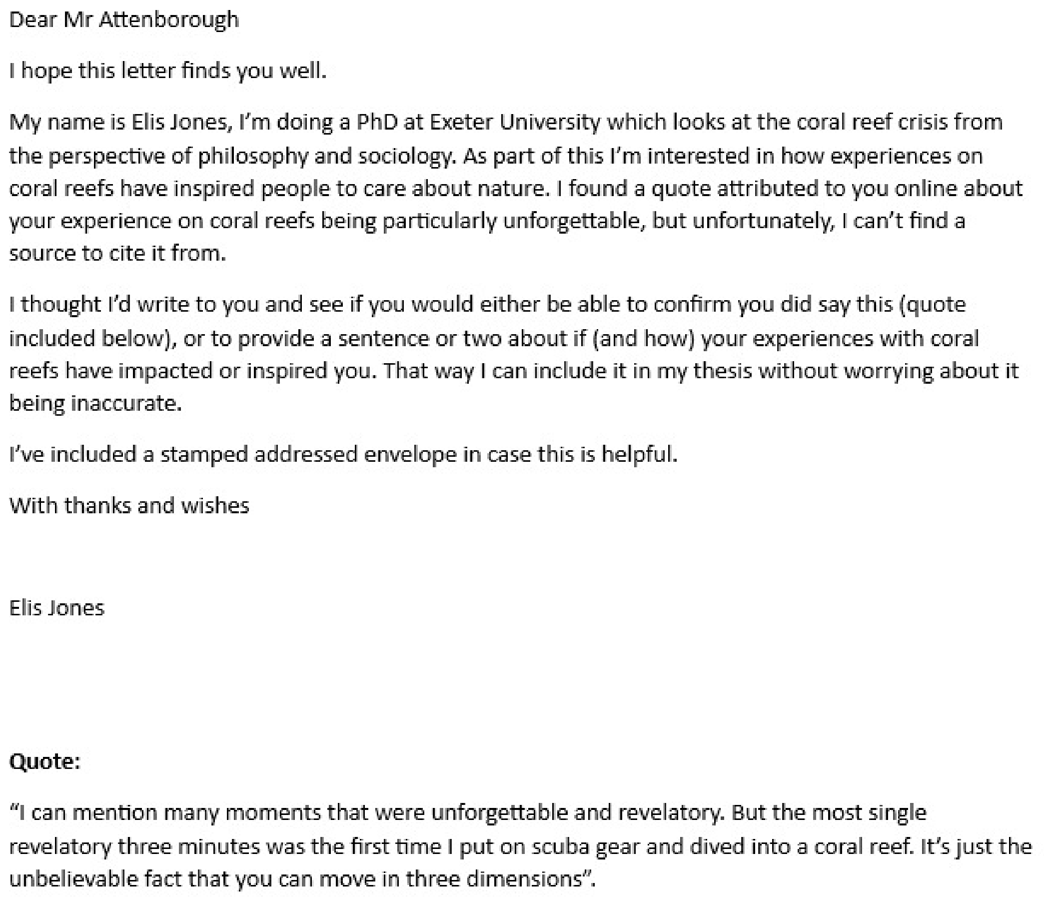
Appendix 2: Table of basic participant demographics

I have not included interviewee participant ID numbers as this may make participants too easy to identify. Career stage is a rough characterisation based on job role and length of career. Discipline is according to the participant's self-description where possible. Many participants used several labels for themselves, which I have tried to capture here by including sub-disciplines. The terms 'marine biologist' and 'marine ecologist' were used synonymously very often, so in these cases I have opted for 'marine ecologist'. The institute listed is the primary institute of the participant (some had multiple affiliations). 'Reef focus' denotes broadly the kind of marine ecosystems that the participant has worked on, distinguished broadly between tropical (warm water) and temperate or cold water reefs (cold water).

Career Stage	Discipline	Sub-Disciplines	Institute	Reef focus
Early	Marine Ecology	Spatial Ecology	UK University	Warm water
Early	Marine Ecology	Functional ecology, some geology	UK University	Warm water
Early	Marine Ecology	Behavioural Ecology	UK University	Warm water
Early	Marine Ecology	Behavioural Ecology	UK University	Warm water
Early	Marine Ecology	Some physical oceanography	UK University	Warm water, cold water
Early	Marine Ecology	Behavioural ecology	UK University	Warm water
Early	Marine Ecology	Reproductive ecology	UK University	Warm water
Early	Marine Ecology		UK University	Cold water
Early	Proteomics		UK University	Warm water
Early	Socio-ecology		UK University	Warm water
Early	Marine Geology		Ireland University	Cold water
Mid	Marine Ecology	Macroecology	USA University	Warm water
Mid	Marine Ecology	Behavioural Ecology	UK University	Warm water
Mid	Marine Ecology	Behavioural ecology	UK University	Warm water
Mid	Marine Ecology	Some molecular ecology, reproductive ecology	UK University	Warm water
Mid	Marine Ecology	Molecular and microbial ecology	UK University	Warm water
Mid	Marine Ecology		UK University	Cold water
Mid	Marine Ecology	Management, policy	UK NGO	Warm water
Mid	Marine Ecology	Macroecology	Mexico University	Warm water
Mid	Marine Ecology	Behavioural ecology, some microecology	Brazil University	Warm water
Late	Marine Ecology		UK University	Cold water
Late	Marine Ecology	Microbial ecology	USA University	Warm water
Late	Marine Physiology		USA University	Warm water
Late	Taxonomy		USA Museum	Cold water
Late	Marine Ecology	Microbial ecology, molecular biology	UK University	Warm water
Late	Marine Ecology		UK University	Warm water

Appendix 3: Personal communication

The following is a letter written by the author to David Attenborough asking about his experiences on reefs (cited in chapter one), along with his response.



Dear Mr Attenborough

I hope this letter finds you well.

My name is Elis Jones, I'm doing a PhD at Exeter University which looks at the coral reef crisis from the perspective of philosophy and sociology. As part of this I'm interested in how experiences on coral reefs have inspired people to care about nature. I found a quote attributed to you online about your experience on coral reefs being particularly unforgettable, but unfortunately, I can't find a source to cite it from.

I thought I'd write to you and see if you would either be able to confirm you did say this (quote included below), or to provide a sentence or two about if (and how) your experiences with coral reefs have impacted or inspired you. That way I can include it in my thesis without worrying about it being inaccurate.

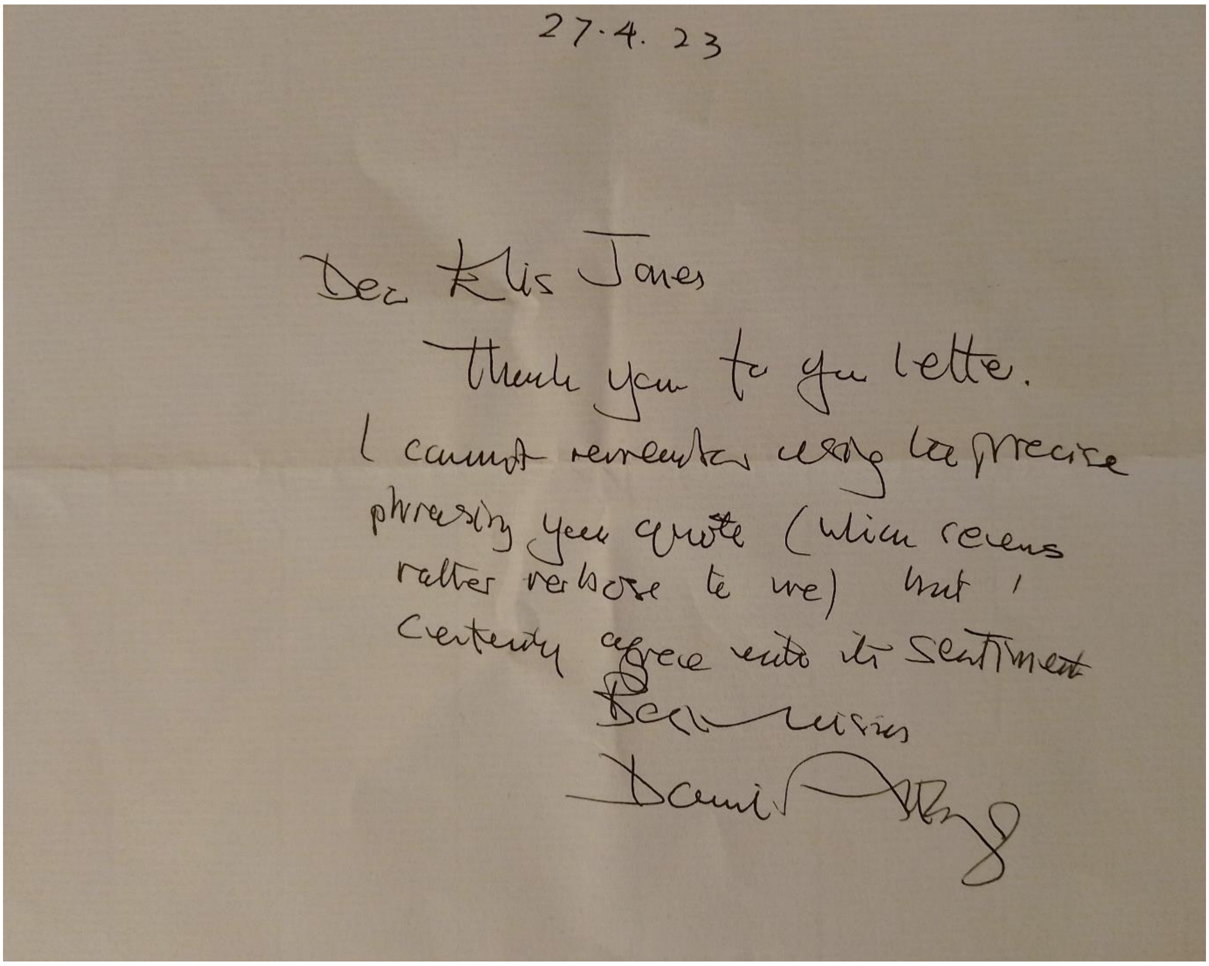
I've included a stamped addressed envelope in case this is helpful.

With thanks and wishes

Elis Jones

Quote:

"I can mention many moments that were unforgettable and revelatory. But the most single revelatory three minutes was the first time I put on scuba gear and dived into a coral reef. It's just the unbelievable fact that you can move in three dimensions".



27.4.23

Dear Miss Jones

Thank you for your letter.

I cannot remember using the precise phrasing you quote (which seems rather verbose to me) but I certainly agree with its sentiment

Best wishes

David Attenborough

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