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Abstract

Amidst global efforts to address biodiversity loss, the concept of 'nature positive' has gained traction as a societal goal aligned with the Global Biodiversity Framework. While the goal is increasingly being embraced by businesses and governments, there has been little scientific investigation into how fisheries, a key sector in the global economy and a major driver of marine biodiversity loss, could contribute to it. In this study, I start filling this gap. I draw on literature on the mitigation hierarchy and transformative actions for businesses to offer a conceptual framework outlining how fisheries' direct operations could contribute to the nature positive goal. I translated the UK government-prescribed 'Defra biodiversity metric' to the context of fisheries and applied it to three contrasting case studies. Via key-informant interviews, I gained (1) insight into stakeholders' perspectives on the relevance of the nature positive goal for fisheries; and (2) feedback on the framework and metric. My findings indicate that my approach could be applied to diverse real-world fisheries as a first step towards nature positive fisheries. However, the results also suggested that the path towards nature positive will differ considerably between fisheries, and knowledge gaps need to be addressed. Finally, stakeholders are overall cautiously optimistic regarding a nature positive goal for fisheries, recognising both its potential benefits and challenges. This study represents a first step towards defining a nature positive pathway for fisheries, with implications for broader marine conservation initiatives.

1. Introduction

The Global Biodiversity Framework (GBF) is an intergovernmental agreement under the Convention on Biological Diversity that has a mission to "halt and reverse biodiversity loss by 2030" and the long-term vision of "living in harmony with nature" by 2050 (CBD, 2022). To contribute to this vision, different sectors will need to address their biodiversity impacts, both by mitigating their current and future negative impacts within their operations and value chain, and taking proactive conservation and restoration initiatives not linked to their impacts (Milner-Gulland et al., 2020). This requires acceptance of net outcome approaches for biodiversity goals, where some biodiversity impacts must be prevented, while others are inevitable and permissible, provided they are counterbalanced by restoration and regeneration (Arlidge et al., 2018).

The framework typically used for planning actions towards net outcome goals is the mitigation hierarchy. This framework has been widely applied in terrestrial systems to balance conservation with economic development in pursuit of a clearly-defined goal (Arlidge et al., 2018). It prescribes four sequential action steps: 1) avoidance of impact as far as possible, 2) minimisation of unavoidable impacts, 3) remediation of impacts that cannot be avoided or minimised, and lastly 4) compensation for any residual impacts (Arlidge et al., 2018). Compensation measures must ideally benefit the same biodiversity components as those affected, i.e. 'like-for-like' (Maron et al., 2024). By following the mitigation hierarchy, the state of biodiversity should in principle be overall 'no worse off' (no net loss), or, if gains exceed any losses, better (net gain) (Fig. 1; BBOP 2012).

However, to achieve the vision of the GBF, commitments to no net loss or net gain at the project level are not enough; positive outcomes are required at a societal scale (Fig. 1; Locke et al. 2021). This thinking underpins the concept of 'nature positive' which is gaining traction as an ambitious goal that directly aligns with the GBF (zu Ermgassen et al., 2022). Like the GBF, nature positive envisions more nature in the future than there is now. To meet the nature positive goal, it will be insufficient to consider only direct biodiversity impacts of economic activities, indirect impacts must also be addressed throughout the entire value chain (zu Ermgassen et al., 2022). Indeed, assessments of companies' footprints across their value chains have revealed that direct operational impacts are a relatively small proportion of organisations' total biodiversity impacts (e.g. Bull et al. 2022). Expectations around extended corporate accountability are also growing, particularly under voluntary and regulatory frameworks such as Science Based Target Networks and Taskforce on Nature-related Financial Disclosures (Booth et al., 2023).

When addressing corporate biodiversity impacts, strong compliance with the mitigation hierarchy is imperative (Maron et al., 2024). However, there is also growing recognition that delivering the GBF and a nature positive future will require transformative change (Booth et al., 2023). Such change will be critical to guard against leakage (i.e., where an individual company's positive actions do not lead to positive outcomes on a societal scale due to market effects or the actions of others), address the underlying drivers of biodiversity loss, and drive system-wide change. The range of possible actions relevant to transformative change has been divided into three categories: (1) private actions, which refers to those an entity makes to reduce their own impacts on biodiversity, such as ensuring no net loss of biodiversity; (2) social signalling actions, which refers to those an entity carries out to signal their opinions and position on biodiversity to others, such as sharing biodiversity goals; and (3) system-changing actions, which refers to those which an entity carries out collectively with others to address structural barriers and opportunities, such as changing policies or sectors (Booth et al. 2023; Naito et al., 2022).

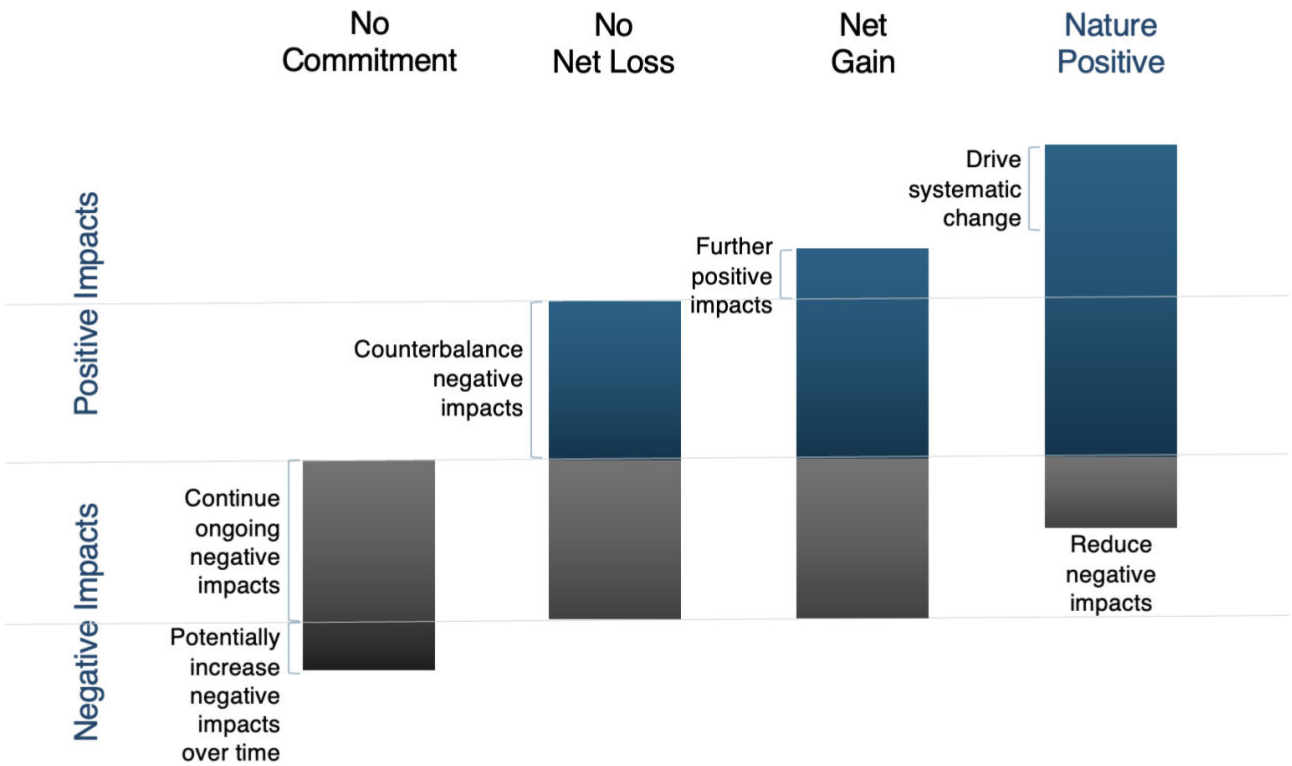

Figure 1. *The relationship between no net loss, net gain and nature positive. Negative and positive impacts are compared against the baseline of a 'No Commitment' scenario, which assumes that current and new negative impacts continue accumulating. 'Drive systemic change' under nature positive refers to driving systemic change to deliver positive outcomes at the societal scale (adapted from Booth, 2024).*

Although nature positive initiatives are becoming widespread throughout the business and political communities (zu Ermgassen et al. 2022), fisheries have received relatively little attention in this context. More generally, it is only relatively recently that there have been attempts to translate net gain approaches to marine systems, mainly centred around mitigating impacts of coastal developments like windfarms (e.g. ABPMer, 2019). It is also only recently that voluntary frameworks like the Science Based Target Networks released guidelines for companies to set targets for the oceans (SBTN, 2023). While fisheries management strategies typically strive to achieve sustainable utilisation of fishery resources, they generally do not aim to deliver net biodiversity outcomes. Further, although there have been recent efforts to use the mitigation hierarchy to address fisheries bycatch (e.g. Squires & Garcia, 2018; Booth et al., 2019), the mitigation hierarchy has not yet been used to address the wider impacts of fisheries on biodiversity - encompassing not just bycatch but also target stocks and habitats. This would be a fundamental step towards aligning fishing with broader biodiversity commitments, including nature positive.

Fisheries are a key part of the global economy and important for global food security (FAO, 2024; Chuenpagdee & Jentoft, 2019), yet also constitute one of the biggest pressures on ocean ecosystems due to overexploitation of fish stocks, impacts on marine habitats, and bycatch of non-target species (Davies et al., 2017; Tursi et al., 2015). By focusing on reducing biodiversity impacts, as well as novel restorative and transformative actions, fisheries could play an important role in marine biodiversity recovery and driving outcomes aligned with the GBF. Further, the fishing industry is particularly interesting in this context because well-managed fish stocks have generally been considered sustainable (Hilborn et al., 1995), but nature positive discourse centres around sectors where human activity is seen as causing harmful impacts that require mitigation.

In this study I explore how fisheries operations could contribute to the societal transition towards a nature positive future. My research questions were:

- How could fisheries operations contribute to the nature positive goal?
- How could the proposed conceptual framework be adapted and applied to real-world fisheries?
- What do key informants think of a nature positive goal for fisheries and the approach proposed in this study?

My focus is the direct effects of fisheries operations on ocean ecosystems and target species. That is, the scope is the impacts of fishing between when fishing gear is cast into the ocean until it is removed, and excludes entire business operations and value chains. While whole value chain approaches are critical to achieving the global nature positive goal, current methods for value chain analysis (e.g. Gardner et al., 2019; Lambin et al., 2018) are just as applicable to fisheries as they are to other industries, so applying them requires less conceptual novelty.

2. Methods

Overview

I first conducted a literature review and key-informant interviews to inform the development of a conceptual framework for how fisheries operations could contribute to the global nature positive goal. To refine the framework and explore how it could be adapted to different fisheries, I then worked through it for three real-world fishery case studies using information obtained from the Marine Stewardship Council. To estimate net biodiversity outcomes for fisheries operations, I adapted the UK's 'Defra biodiversity metric' to the context of fisheries (Natural England, 2023). I then assessed suggested mitigation measures for each case study in terms of socio-economic feasibility. Finally, I conducted key-informant interviews with fisheries and biodiversity net gain experts to gain insight into their views on the relevance of the nature positive goal for fisheries and feedback on the metric proposed in this study (Fig. 2). This study was carried out in accordance with my CUREC Ethics permission, reference number: R91741/RE001.

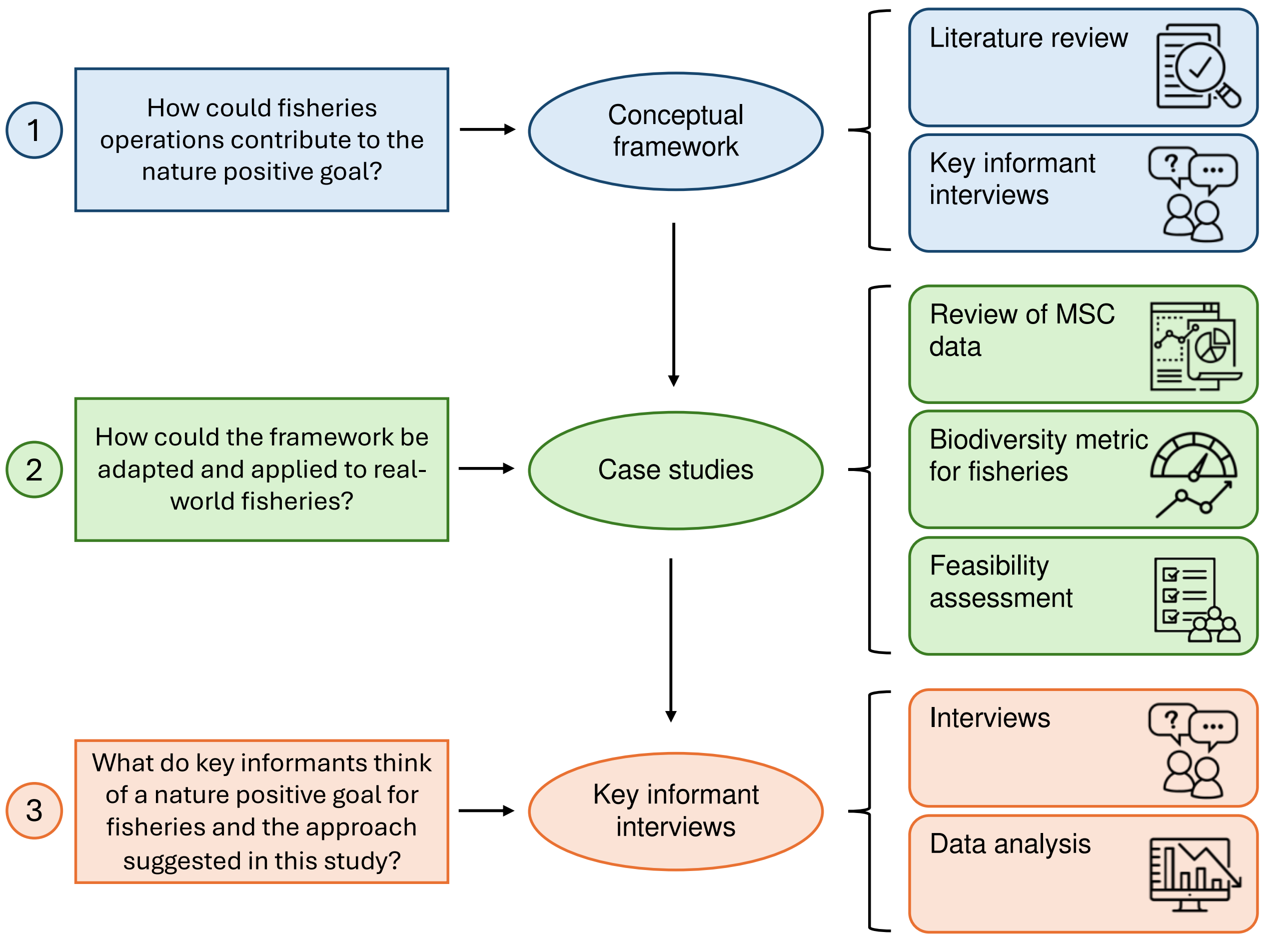

Figure 2. *A flow diagram to illustrate my methodological steps. The square boxes refer to my research questions. The round boxes are the methods I used to answer each question. The square boxes with curved edges are the specific methodological steps taken for each question.*

2.1 Conceptual framework

This conceptual framework expands mitigation hierarchy frameworks for bycatch (Squires & Garcia, 2018; Milner-Gulland et al., 2018; Booth et al., 2019; Gupta et al., 2020) to address all direct impacts of fisheries operations on target species and ocean ecosystems. Because the framework aims to deliver outcomes aligning with the nature positive goal, I added an additional step for transformative actions for biodiversity, as described by Booth et al. (2023).

I first conducted a non-systematic literature review, with two aims. Firstly, to gather insights from previous applications of the mitigation hierarchy in other sectors, and previous approaches to setting robust biodiversity goals and targets with clear outcomes. Secondly, to classify existing fisheries measures under the steps of the mitigation hierarchy, by exploring the literature on approaches which are already applied to mitigating fisheries impacts on biodiversity (see Appendix VII for more details).

To gain a deeper insight into fisheries management and associated challenges, I conducted eight interviews with experts from the Fisheries Standard Team in the Science and Standards Department of the Marine Stewardship Council (MSC). The MSC is the leading wild-capture fishery sustainability certification programme (UN, 2022). The interviews followed broad pre-determined discussion points centred around fisheries management approaches and challenges to implementing novel management measures in the real-world.

I used the information from the literature review and interviews to create a preliminary conceptual framework, which I updated iteratively as I gathered more information and tested it on case studies, to produce the final version presented here.

2.2 Case studies

To explore the utility of the conceptual framework and refine it, I worked through each step for three real-world fisheries. I chose MSC-certified fisheries as case studies because secondary data is readily available in online certification reports, gathered by third-party auditors and subjected to peer-review. The reports contain both quantitative and qualitative data on MSC-certified fisheries' impacts on biodiversity, ecological condition of impacted biodiversity components, and details of fisheries management strategies (MSC, 2023). Additionally, an MSC-certified fishery is a defined, geographically-limited operation that has already demonstrated commitment to sustainable practices, so the scope of the impact can be assessed, and they are more likely to be interested in supporting a nature positive goal. To explore how the framework could be applied to various contexts, I chose three contrasting fisheries in terms of the gear used and impacts on biodiversity (Table 1).

Table 1. *General information about the MSC-certified fisheries used as case studies*

Case study	Gear type	Geographical location	Vertical zone	No. of bycatch species	Link to MSC certification page
Bluefin tuna *(Thunnus thynnus,* Linnaeus, 1758)	Handline and rod, greenstick	Spain	Pelagic	0	https://fisheries.msc.org/en/fisheries/jc-mackintosh-greenstick-handline-and-fishing-rod-bluefin-tuna-fishery/
King scallop *(Pecten maximus,* Linnaeus, 1758)	Scallop dredge	Scotland	Benthic	60+	https://fisheries.msc.org/en/fisheries/ssmo-shetland-inshore-brown-crab-and-scallop/
Orange roughy *(Hoplostethus atlanticus,* Collett, 1889)	Bottom trawl	New Zealand	Benthic (deep-sea)	10+	https://fisheries.msc.org/en/fisheries/new-zealand-orange-roughy/

2.3 Biodiversity metric for fisheries

A key step of the conceptual framework is a technical assessment of the effectiveness of management measures in mitigating biodiversity impacts, to provide guidance to fisheries on the biodiversity gains they would need to demonstrate to compensate for losses. I first reviewed the literature on existing metrics, from which I chose the 'Defra Biodiversity Metric', which is prescribed by the UK government for use in their terrestrial Biodiversity Net Gain policy (Natural England, 2023), as a well-documented and influential metric that could be applicable to a fisheries context.

2.3.1 Review of metrics

To identify suitable metrics to adapt for use in the technical assessment, I conducted a literature review of existing metrics based on the criteria outlined by Jones et al. (2011) for desirable characteristics of biodiversity indicators. These include cost-effectiveness, coverage of diverse taxonomic groups, reliability in assessing underlying biodiversity components, and applicability across scales. I also specifically considered the potential of the metrics reviewed to be adapted to the fisheries context. Although, like any biodiversity metric, the Defra metric has been subject to criticism (zu Ermgassen et al. 2021; Duffus et al. 2024), I concluded *a priori* that it was likely to meet most of the criteria outlined by Jones et al. (2011) relatively well when used in the fisheries context and that it could be adapted for fisheries operations (see Appendix I for more details).

2.3.2 Overview of the Defra biodiversity metric

The Defra metric (the UK's Statutory Biodiversity Metric for Biodiversity Net Gain, Version 4.0; Natural England 2023) is used to calculate losses and gains of biodiversity before and after a development takes place, to predict whether the development will deliver at least 10% biodiversity net gain. The metric uses inputs including habitats' ecological condition, area size, distinctiveness, and strategic location of a site to produce an overall biodiversity score. The data used include qualitative judgements of the condition and classification of habitats by ecologists, quantitative data on the size of relevant habitats, and landscape-scale information. These data are integrated into the metric with pre-set scores for habitat types and condition, and used to calculate a pre-development baseline score for biodiversity to compare with a future post-development score to predict (ex-ante) whether biodiversity net gain will be delivered (Fig. 3). The post-development calculation uses the same formula but incorporates risk multipliers, i.e. factors by which gains are required to be larger than associated losses to account for risks. These multipliers capture elements including risk of project failure and estimated time a habitat will take to reach the required condition (Natural England 2023; zu Ermgassen et al. 2021).

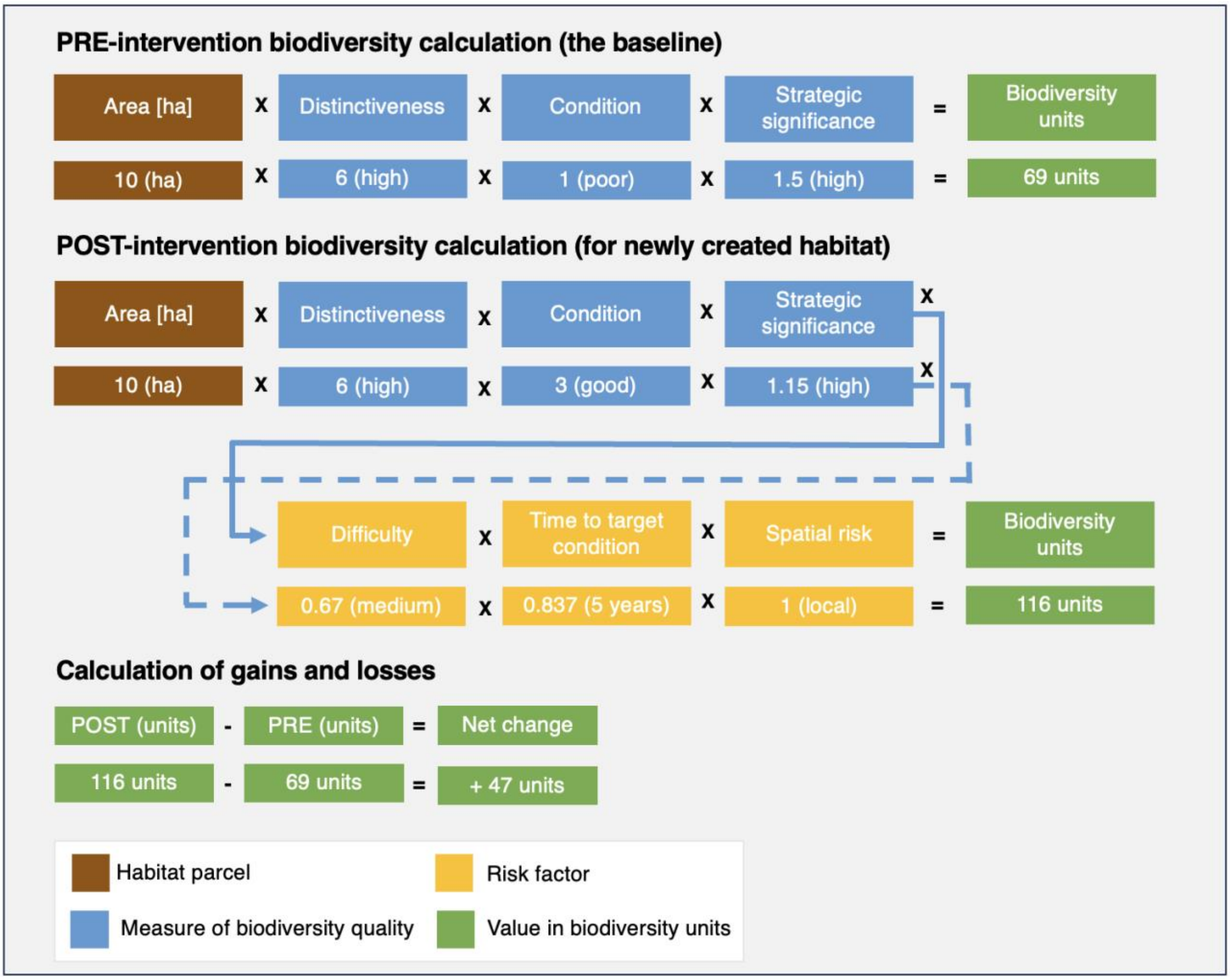

Figure 3. *An overview of the calculations of the Defra biodiversity metric (4.0 version): a pre-intervention biodiversity calculation (the baseline), a post-intervention biodiversity calculation (for newly created habitat), and a final calculation of gains and losses that compares the two to predict the net change in biodiversity before and after development (adapted from Natural England, 2023).*

2.3.3 Overview of the fisheries metric

The metric I developed for fisheries adopts the principles of the Defra metric to predict whether an activity will deliver a 10% net gain. However, recognising ecological and contextual differences between terrestrial developments and fisheries operations, and knowledge gaps in marine systems, I made several adjustments and assumptions.

My fisheries metric calculates scores for both species and habitats, rather than just habitats as in the Defra metric. The literature supports the importance of including species as their response to biodiversity impact is not well captured in habitat-only metrics (Hawkins et al., 2022), including in marine systems (Hooper et al. 2021). Doing so also facilitates using the metric for fisheries with direct impacts on species but minimal habitat impacts, such as many pelagic fisheries, and ensures that compensation measures adequately mitigate impacts on species by mandating actions that directly benefit affected species. These actions may include prioritising habitat creation for impacted species and contributing to species restoration initiatives such as oyster seeding. Analogous to how the Defra metric does not combine scores for habitats, hedges, and watercourses because they are based on different criteria (Natural England, 2023), the fisheries metric does not combine the scores for species and habitats. Instead, both components need to deliver 10% biodiversity net gain separately.

A key assumption of the fisheries metric is that fisheries operations are assumed to deliver no net loss of biodiversity if they meet the criteria for the maximum score against the MSC Fisheries Standard for the fishery's impacts on species and habitats. The MSC Fisheries Standard scores habitats and species separately on their status, management strategy and quality of available information (MSC, 2023). The assumption of a link between MSC scores and no net loss is, in turn, based on the assumption that sustainably managed fisheries deliver no net loss. However, it should be noted that, although the MSC Standard does require regulations focusing on avoidance and minimisation, the standard is not designed to deliver no net loss. Therefore, these assumptions would need to be scientifically tested and potentially replaced if the metric were to be implemented for real-world use.

The fisheries metric includes an additional step that predicts the biodiversity score of an improved management scenario. I added this step to predict the effectiveness of steps 1-3 of the mitigation hierarchy (avoid, minimise, and remediate) separately to step 4 (compensation). This score for improved management is subjected to a temporal multiplier to account for the time it would take biodiversity to recover after management has been improved. It is then combined with the score for on-site compensatory actions, and the two are compared to the required score for 10% net gain (Fig. 4; see Appendix II for equations).

The criteria used to score the inputs of the habitat component of the metric are similar to the Defra metric. However, the criteria used for the inputs in the species component differ as follows: The distinctiveness category is based on the extinction risk of species, so it is more closely linked to threats to the species. Additionally, area size is replaced by annual catch of the fishery for each species in tonnes. The annual catch is required to allow quantification of how much species compensation is required. As seeking expert judgement and conducting site visits was not within the scope of this project, alternative information had to be used to score the inputs (Table 2; see Appendix III for more details on the metric).

Calculation of gains and losses

Post-intervention units for improved management + **Post-intervention units for compensation** - **Baseline habitat/species units** = **Net change**

Table 1. Example from king scallop fishery: number of baseline (pre-intervention) units

Habitat type	Area [ha]	Habitat distinctiveness	Habitat condition	Strategic significance	Baseline habitat units
Mixed sand	82	2 (low)	2 (good)	1.15 (high)	377
Gravel	35	2 (low)	2 (good)	1.15 (high)	162
Species	**Annual catch [t]**	**Species distinctiveness**	**Species condition**	**Strategic significance**	**Baseline species units**
King scallop	1072	1 (least concern)	2 (good)	3 (high)	3216
Horse mussel	118	2 (near threatened)	2 (good)	1 (low)	1418

Figure 4. *Overview of the calculation within the fisheries metric to predict net change. The equation depicted (green square boxes) is calculated for habitats and species separately. The table shows an example of the inputs and score for a baseline (pre-intervention) calculation in the fisheries metric for the habitats and some of the species impacted by the king scallop fishery, one of the three case studies used in this study. For full details of the fisheries metric, including the equations for each calculation, see Appendix II & III).*

Table 2. *A comparison of the inputs and the information used to score the inputs for the Defra metric and the metric for fisheries (for both habitats and species). See Appendix III for more details.*

Defra metric habitat inputs	Fisheries metric habitat inputs	Fisheries metric species inputs
Habitat **distinctiveness**, based on expert judgement	Habitat **distinctiveness**, based on available literature	Species **distinctiveness**, based on the IUCN Red List category
Habitat **condition** based on judgements from ecological consultants	Habitat **condition**, based on the MSC habitat score	Species **condition**, based on the MSC species score
Size of the **area** of habitat impacted [ha], based on quantitative data	Size of the **area** of habitat the fishery impacts [ha], based on MSC reporting	Annual **catches** [t] of the species by the fishery based on MSC reporting
Strategic significance, based on location and habitat type (e.g. in Local Nature Recovery Network)	**Strategic significance,** based on whether the site is within or near a protected area or a buffer zone	**Strategic significance**, based on whether a species is considered a keystone species

2.3.4 Sensitivity analysis

To address uncertainties in scoring certain metric inputs for the case studies, I conducted a sensitivity analysis. Following the approach outlined in The International Union for Conservation of Nature (IUCN) Red List guidelines for handling data with uncertainty (Akçakaya et al., 2000), I went through the following steps for each case study: (1) identify input scores with associated uncertainties; (2) determine a best estimate and a feasible range of scores for each input based on MSC assessment reports and the wider literature; (3) run three simulations: one with all inputs set to their best estimate, one with each at the upper limit of their feasibility range (the worst case scenario), and one with each at their lower limit (the best case scenario). If the feasible range or the best estimate qualified a species or habitat for multiple input scores, the more precautionary scenario was used. The output of this analysis consisted of a best estimate and a range of plausible values for the biodiversity scores for each case study, demonstrating the uncertainty associated with each score.

2.4 Feasibility assessment

To account for the socio-economic complexity of fisheries when exploring management measures, the conceptual framework includes a feasibility assessment. Drawing on previous studies (Gupta et al. 2020; Williams et al., 2021), I evaluated the feasibility of implementing each measure in terms of the socio-economic impact on fishers and likelihood of compliance for the case studies. The necessary technological and institutional conditions for each measure were also considered. For each case study, I conducted a semi-quantitative assessment of the feasibility of measures based on available literature for the fishery and used a simple "traffic light" categorisation system. I then sought validation for my decisions with experts in the Science and Research Team at the MSC.

2.5 Key-informant interviews

2.5.1 Interview approach

To gain a preliminary impression of how the idea of nature positive fisheries would be received by the fishing industry and gain feedback on the metric, I conducted structured interviews. I purposively selected experts on fisheries and biodiversity net gain rather than seeking a comprehensive or representative sample. The key-informants included fisheries experts (n=7) and experts on biodiversity net gain (n=6) from diverse sectors. As the biodiversity net gain experts were selected for their expertise on the Defra metric, they were all based in the UK. The fisheries experts were selected based on their professional experience of working with fisheries, both within the UK (n=4) and globally (n=3; Spain, Canada and New Zealand).

I developed two structured interview questionnaires tailored to the expertise of the key-informants. The interviews lasted 30-40 minutes and were conducted online or in-person, depending on the location of the participant. Before the interviews, participants were emailed background information, which was discussed at the start of the interviews. The interviews primarily consisted of open-ended questions and were divided into two parts: (1) the concept of nature positive fisheries; and (2) the proposed metric. Interviews with fisheries experts primarily focused on (1), whereas interviews with biodiversity net gain experts focused on (2). I wanted to understand whether the nature positive concept resonated with the fisheries experts and how they thought it could be operationalised. In contrast, I sought feedback from biodiversity net gain experts on the extension of the Defra metric to the fisheries context (see Appendix V for interview questions).

2.5.2 Data Analysis

I thematically analysed the open-ended, qualitative data from the interviews using NVIVO. Following Gupta et al. (2022), I used a hybrid approach that combined deductive and inductive coding. For example, responses on 'operationalising the nature positive fisheries goal' and 'the feasibility of real-world adaptation of the metric' were deductively coded based on *a priori* codes. I then inductively added new themes that emerged during the analysis, such as 'suggested steps forward to operationalise the metric' and 'framing the goal for uptake' (see Appendix VI for codebooks).

3. Results

3.1 The proposed conceptual framework

The proposed conceptual framework for how fisheries operations could contribute to the nature positive goal has seven steps: (A) define the system; (B) set a goal; (C) explore mitigation measures; (D) explore transformative actions; (E) evaluate the effectiveness of measures; (F) make a management decision; and (G) implement, monitor, and adapt (Fig. 5).

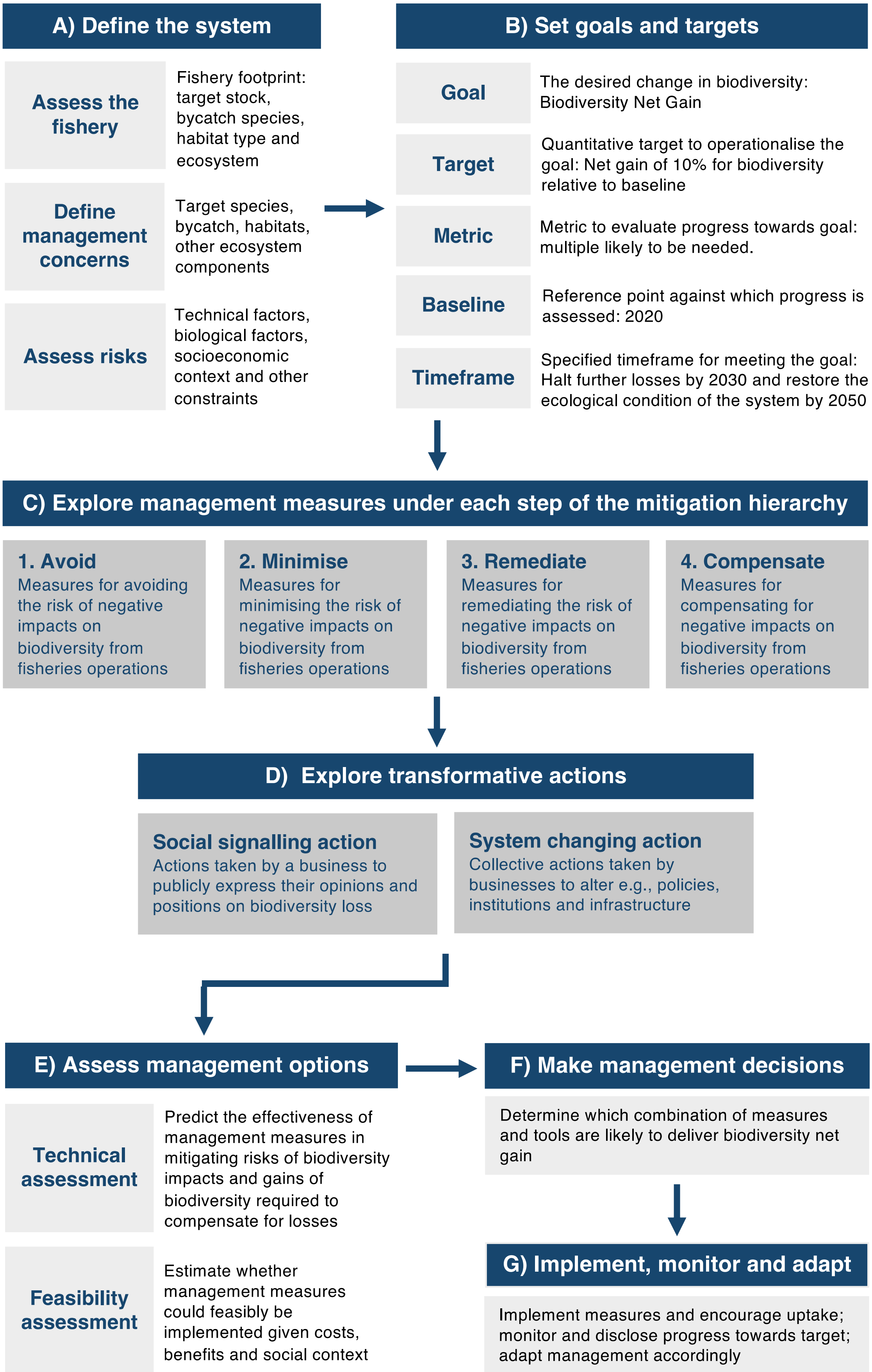

Figure 5. *The proposed conceptual framework for actions towards nature positive fisheries operations. The framework prescribes using the mitigation hierarchy to deliver biodiversity net gain from direct fisheries operations and taking additional transformative actions to drive positive outcomes at the societal scale.*

3.2 Case study results: Applying the conceptual framework

I applied the framework to three distinct fisheries targeting bluefin tuna, king scallop and orange roughy respectively. This was done to refine the framework and metric and explore their utility (Fig 6; see Appendix VIII for detailed reports for each fishery).

3.2.1 Case study results for steps A-D

At step A (define the system; Fig 5), the three fisheries were found to have very different footprints. The bluefin tuna fishery primarily impacts the tuna stock, with minimal direct benthic habitat impacts, and negligible bycatch attributed to the use of selective fishing gear (Borges and Revenga, 2022). Conversely, both the orange roughy and king scallop fisheries have multiple bycatch species and use fishing methods that directly damage the seabed (Cappell et al., 2018; Punt et al., 2022). The orange roughy fishery operates over a larger benthic area than king scallop and operates in the deep-sea where recovery times for impacted seabed features are poorly understood (Punt et al., 2022). Consequently, while the primary concern in the tuna fishery is the tuna stock; habitat, target species and bycatch are all of concern in the orange roughy and king scallop fisheries. Risks to biodiversity across these fisheries include biological risks (e.g. long life-history of orange roughy) and technical risks (e.g. encounterability of bycatch species for scallop and potential for overfishing due to insufficient information for tuna; Borges and Revenga, 2022; Cappell et al. 2018; Punt et al. 2022). Socio-economic risks and other constraints, particularly related to monitoring and budgets, may also exist but these could not be adequately assessed due to limited information.

Step B involves setting biodiversity goals, quantitative targets, a baseline, and timeframe for each case study. The goal for desired change in biodiversity, quantitative target and timeframe are as prescribed in the general framework (Figs. 5, 6). However, because the information used for the case studies was based on the report from their latest MSC certification report, the baseline year for the goal had to be adjusted for each fishery. To monitor future biodiversity outcomes, indicators for population growth rate and range, species richness and relative abundance, and seabed integrity are potentially applicable.

For step C (management measures), I used information from the fisheries' MSC certification reports on the criteria which each fishery could undertake to attain the maximum score against the MSC Fisheries Standard for habitats and species (which would constitute no net loss within my framework), and categorised them against the steps of the mitigation hierarchy. The measures proposed included: spatio-temporal closures (avoidance); gear changes (minimisation); improved release protocols for bycatch (remediation); and contributions toward habitat restoration (compensation). Additionally, each fishery would need to address any remaining uncertainties regarding the impacted biodiversity to better inform their management strategy.

Following Step D of the framework, recommendations for transformative actions were made for each fishery. These included sharing biodiversity goals and strategies, supporting measures to combat illegal, unreported, and unregulated fishing (IUU) of target species and advocating for benthic protected areas. However, although transformative actions are imperative in driving fisheries towards the nature positive goal, their effectiveness could not be assessed here due to lack of quantifiable data on their impact for biodiversity.

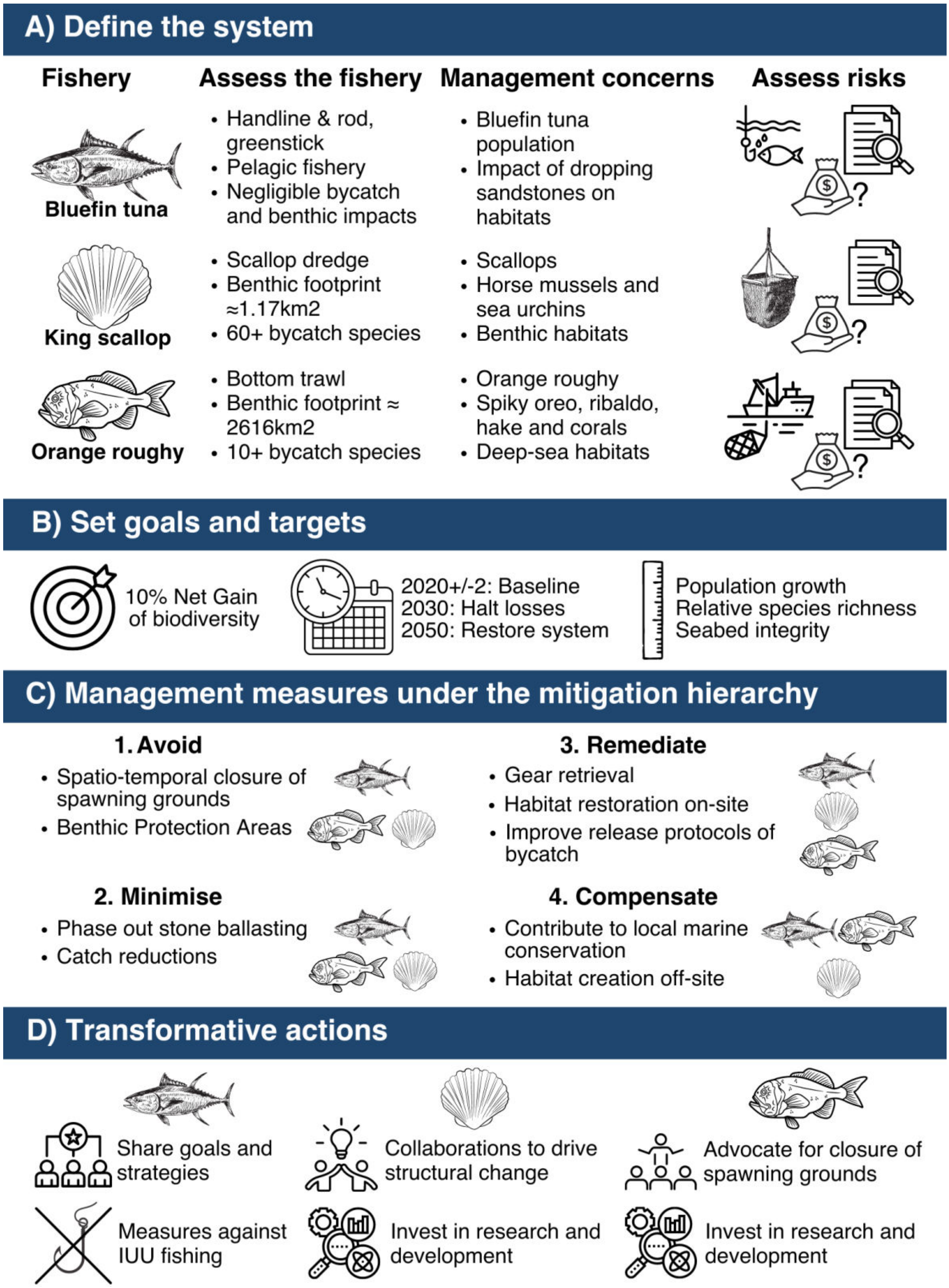

Figure 6. *Overview of the results from steps A-D of the conceptual framework for the three fishery case studies in the following order: Bluefin tuna fishery, king scallop fishery and orange roughy fishery. IUU fishing is the acronym for Illegal, Unregulated and Unreported fishing. The icons under 'Assess risks' refer to some of the risks to biodiversity due to the fisheries operations for each case study. These include risk of encounter with fishing gear and overfishing (fishing gear icons), potential socio-economic risks ($ icons), and risks associated with uncertainties and knowledge gaps (magnifying glass icon). Figure created using canva.com.*

3.2.2 Preliminary results from the fisheries metric (Step E)

Using the fisheries metric, I predicted the ex-ante effectiveness of management measures in mitigating risks of biodiversity impacts and delivering the biodiversity gains required to compensate for losses (Fig. 7). The sensitivity analysis showed that the outputs for the bluefin tuna fishery had a relatively small range of feasible values due to relatively little uncertainty in the inputs of the score. The orange roughy fishery and the king scallop fishery had larger ranges of feasible values. This was particularly true for the outputs of the compensation calculation for the king scallop fishery (see Appendix IV for detailed outputs of the sensitivity analysis).

<u>King scallop fishery</u>

Preliminary results predicted that the king scallop fishery could reach net gain for the primary impacted species and habitats by adopting management measures including benthic protection areas, catch reductions and habitat creation (Fig. 7). The fishery would also have to address remaining uncertainties for impacted biodiversity to better inform their management strategy. Two specific compensation measures are proposed from which the fishery would choose one to reach net gain for their operations:

(1) Habitat creation within the current fishing area (on-site) of 280 hectares of good condition gravel habitat and seeding for scallops. This compensation option is expected to benefit king- and queen scallops directly but not horse mussels and sea urchins.
(2) Habitat creation of 850 ha of maerl beds and 800 ha of horse mussel beds in an area adjacent to the current fishing area (off-site). This would require seeding of horse mussels and potentially also for king- and queen scallops. This compensation option is expected to benefit all directly impacted species, except sea urchins.

<u>Orange roughy and tuna fisheries</u>

In contrast, the analysis suggests that, based on currently available information, both the orange roughy and tuna fisheries are unable to deliver biodiversity net gain for the impacted species and habitats (Fig. 7). This stems from a lack of known compensation measures that could directly benefit the biodiversity affected by these fisheries. However, while 'like-for-like' compensation measures do not currently exist, this does not preclude fisheries taking positive action for biodiversity. For instance, both fisheries could take each of the following steps to deliver an overall positive contribution to biodiversity, even if they are not able to deliver biodiversity net gain in the strict sense:

(1) Prevent and remediate impacts on biodiversity as much as possible.
(2) Support research and development into potential compensation measures to address the knowledge gaps and reduce uncertainties.
(3) Take more general positive actions known to benefit marine biodiversity (e.g. contribute to nearby restoration projects focused on other biodiversity components).

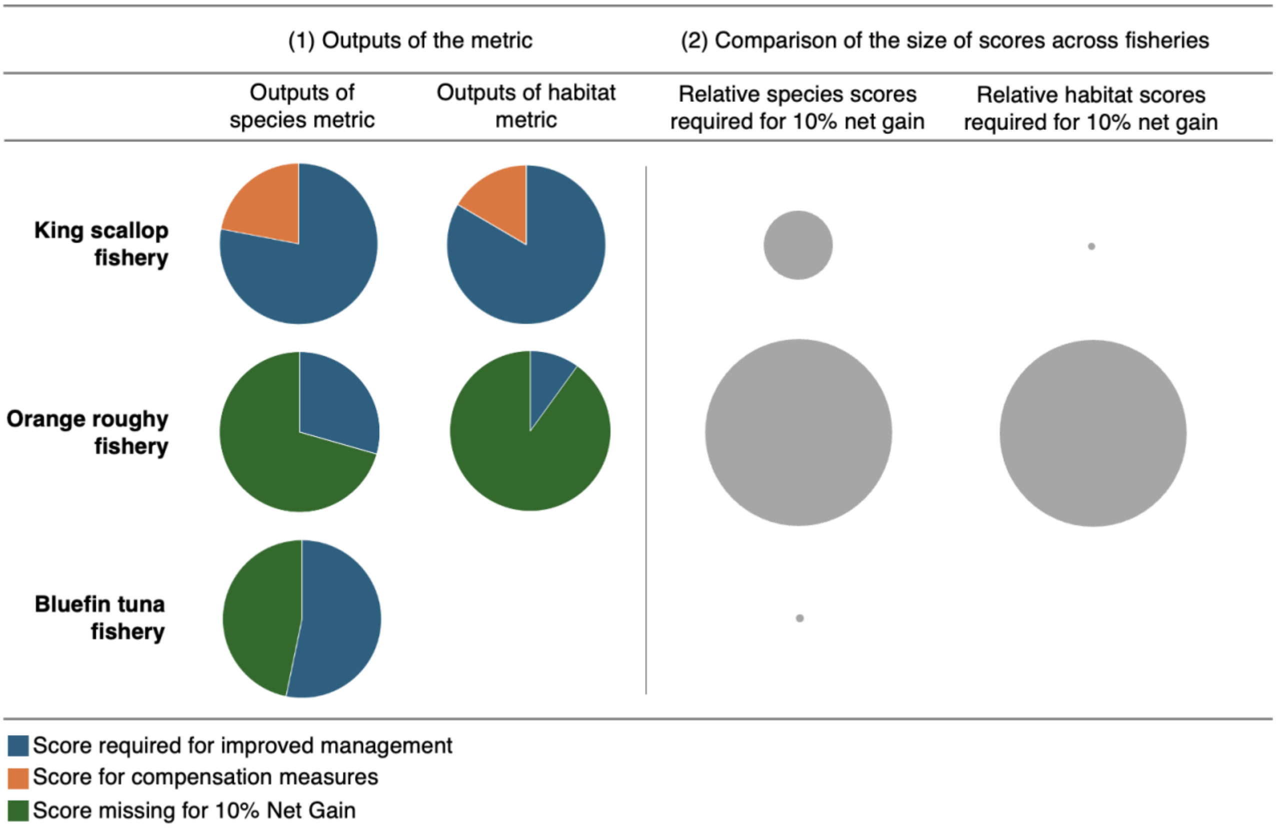

Figure 7. *Metric results for the three fisheries. (1) Pie charts show the metric outputs for the species and habitat components, for each fishery. The total area of each pie chart represents the score required for 10% net gain for each respective fishery for either habitats or species. Blue represents the score delivered through improving management according to the first three steps of the mitigation hierarchy (avoidance, minimisation, remediation). Orange represents the score delivered through the final step of the mitigation hierarchy (compensation), where relevant. Green areas represent biodiversity impacts that can't be directly compensated for at present. Additional positive actions for biodiversity could be undertaken to compensate for these impacts but they do not represent net gain because they would not improve the status of the impacted species/habitats directly. (2) The proportional area chart demonstrates how the size of the scores required for 10% net gain for habitats and species compare across the three fisheries. That is, the size of the circles is scaled across fisheries for habitats and species separately (because the two are based on different criteria), so the largest score for each (in both cases orange roughy) is 1 and the size of the other circles is relative to this score.*

3.2.3 Feasibility assessment of management measures (Step E)

Following step E of the conceptual framework, the feasibility of implementing the proposed management measures was assessed (Table 5; see Appendix VIII for details). The measures in the table that follow the steps of the mitigation hierarchy are incorporated in the metric and need to add up to enough biodiversity benefit to more than compensate for calculated impacts to meet 10% net gain. The measures in the final two columns of the table, i.e. the 'Transformative actions', are additional steps required to move towards nature positive, but these cannot substitute for the impact mitigation steps. Overall, most of the suggested measures were estimated as medium feasibility, with only one measures considered of low feasibility and three of high feasibility. The measures considered of high feasibility were transformative actions that do not involve high costs or effort from the fishery. The feasibility assessment was done by me for illustrative purposes, based on literature and consultation with MSC experts; best practice would have been to carry out an extensive stakeholder consultation exercise.

Case study		Avoid	Minimise	Remediate	Compensate	Transformative actions	
Atlantic bluefin tuna 	**Potential measure**	**Spatio-temporal closure of tuna spawning grounds**	**Phase out stone ballasting**	**Habitat improvement efforts on-site (removal of sandstones dropped)**	**Fine/tax for impacts**	**Investment in research and development**	**Measures against illegal, unreported and unregulated fishing**
	Feasibility assessment	E: Some evidence of potential economic benefits; T: Costly monitoring and enforcement required but Spanish EM programmes may aid implementation I: Policy required; S: Reduction in catches expected, potential for fisher resistance	E: The fishery might be able to maintain the same catches using its other gear types; T: Additional monitoring or incentive may be needed; I: Policy could aid implementation; S: Potential fisher resistance, change required	E: Direct costs and/or time and resources required, but may be feasible; T: Additional monitoring and enforcement required, and potentially new technologies ; I: Administrative support needed; S: Novel measure, potential fisher resistance	E: The fishery may have enough resources to pay; T: Costly monitoring may be necessary; I: Policy and administrative support required for implementation; S: Potential fisher resistance to paying	E: The fishery may have enough resources, could support long-term sustainability; T: None expected; I: Collaborations with research institutes required; S: No specific issues identified	E: Requires resources but may be feasible; potential long-term benefits for bluefin tuna population if successful; T: ?; I: Administrative support necessary; S: No specific issues identified
		√√	√√	√	√√	√√√	√√
King scallop 	**Potential measure**	**Spatio-temporal closure**	**Scallop catch reduction**	**Payment for biodiversity restoration on-site**	**Payments-in-kind**	**Collaborations to drive new more biodiversity-friendly policies**	**Share biodiversity goals and strategies with others**
	Feasibility assessment	E: Some areas open to the fishery remain unfished - potential for additional closures without significant cost; T: Current monitoring system applicable; I: Policy required; S: An already established measure, minimal change required if implemented in areas currently not fished	E: Short-term finanical losses anticipated; unclear comparison with long-term gains; T: Current monitoring system applicable; I: Policy ideally required; S: An already established measure, minimal change required	E: Costly for the fishery but may have revenues to pay; T: Current monitoring system applicable; I: Administrative support needed; S: Change requried, potential for fisher resistance	E: Fishers may be able to pay in kind, time and knowledge required. T: Current monitoring system applicable; I: Collaborations with relevant organisations required; S: Novel measure, potential for fisher resistance	E: Time and some resources required but may be feasible; T: Online or in-person meetings both possible; I: Goal is passage of policy by local administration; S: No specific issues identified	E: Low resource requirements; T: Online and/or in-person options feasible; I: Administrative support not expected to be required; S: No specific issues identified
		√√	√√	√√	√√	√√	√√√
Orange roughy 	**Potential measure**	**Benthic Protection Areas**	**Orange roughy catch reduction**	**Best handling and release protocols for bycatch species**	**Contribute to nearby marine conservation efforts**	**Advocate for closures of spawning grounds**	**Investment in research and development**
	Feasibility assessment	E: Not all areas open to the fishery are currently fished, potential for additional protected areas at low cost; T: Current monitoring system applicable; I: Policy required; S: An already established measure, minimal impact on fishers if implemented in areas currently not fished	E: NZ$1.21m short-term loss; unclear comparison with long-term gains; T: Current monitoring system applicable; I: Quota recently increased, most cautious option suggested no change; S: Quota changes are common in this fishery but some resistance expected	E: No extra costs expected but time, knowledge and effort required; T: Current monitoring system applicable; I: Not necessarily required but could support implementation; S: Some change required, potential issues around compliance	E: Fishery may afford costs; T: Current monitoring and enforcement system applicable; I: Policy and administrative support required; S: Novel costly measure, potential fisher resistance	E: Requires time and resources, but may be feasible; potential long-term benefits if succesful; T: Advocating possible online or in-person; I: Ultimate goal is policy passage by local administration; S: No specific issues identified	E: The fishery may have enough resources to make a contribution, could support long-term sustainability; T: None expected; I: Collaborations with research institutes required, these may already exist; S: No specific issues identified
		√√	√√	√√	√√	√√	√√√

Table 5. *A semi-quantitative traffic-light categorisation to summarise the outcome of the feasibility assessment for the main suggested measures in each case study based on available information and expert opinion. Green colour and three "√" symbols indicate a high perceived effectiveness for that measure in that case study, whereas red colour and one "√" symbol a low effectiveness. E stands for the criteria for economic feasibility, T for technological feasibility, I for institutional feasibility and S for social feasibility. EM programme under bluefin tuna refers to electronic monitoring programmes.*

3.3.4 Make a management decision & implement, monitor and adapt (steps F-G)

Finally, the information gathered needs to be synthesised to make a management decision for the fishery and implement it. To assess progress towards the biodiversity goal after measures have been implemented, and to inform changes in the management strategy based on new findings, robust monitoring and research will be critical. Continually assessing progress and adapting management approaches accordingly will be particularly important for first attempts at implementing the framework to start filling in the knowledge gaps.

3.3 Key-informants' opinion of a nature positive goal for fisheries and feedback on the proposed approach

Different stakeholder groups in the fishing sector (i.e. fishers, fishery managers, and the interviewees) had quite different perspectives, so responses from different stakeholder groups were coded separately.

3.3.1 Stakeholders' perception of a nature positive goal for fisheries

Stakeholders with positive perceptions of the nature positive goal cited its alignment with international agreements, ecosystem-based management, and the fishing industry's awareness of the importance of healthy ecosystems for fisheries. Conversely, negative responses indicated that because fisheries already feel under pressure, they are likely to resist any new initiatives that might impede their activities. Lastly, mixed responses conveyed a positive perception of the goal but also some reservations. These included that it might be too aspirational given the current state of fisheries and uncertainties around how it could apply to fisheries given their extractive nature. Two respondents indicated that industry would be reluctant to take on a nature positive ambition because they have already been exposed to many similar goals, targets and phrases which did not lead to change (Table 4).

Table 4. *Responses of fisheries experts relating to their perception of the nature positive fisheries goal and the expected perception of others in the industry, classified into three sentiments and the reasoning they articulated. Example quotes are provided for each reasoning.*

Response	Articulated reasoning	Example quotes
Positive sentiment (24%)	Link to international agreements	*"Nature positive fisheries is a concept that fits really well with the primary legislation and ambitions that the UK has signed up to globally"*
	Link to ecosystem-based management	*"Governance bodies are struggling with ecosystem-based fishery management, what it means, how to implement it and so on"*
	Importance of healthy ecosystems	*"I think everybody recognises that a healthy ecosystem is required to have a vibrant fishing industry"*
Negative sentiment (5%)	Added pressure on industry	*"At the moment the most likely response from industry would be to resist anything that might impede their activities and their businesses"*
Mixed sentiment (71%)	Monitoring and compliance	*"This falls into a conversation that has a lot of friction in terms of compliance"*
	Extractive nature of fisheries	*"How could you achieve nature positive when the whole aim is to reduce and take out?"*
	Existence of related terms	*"I find the concept interesting, but there are many initiatives of this kind"*
	Dependent on impact on industry	*"I think it all depends on what the what the criteria is for the fishing industry to actually achieve the nature positive goal. That's what it will largely depend on how I think it will be perceived."*
	Aspirational	*"It it's not something that would be easy to achieve I guess, in the sphere that I work in at least, because we're quite a long way from that."*

3.3.2 Operationalising a nature positive goal for fisheries

Three themes emerged for framing a nature positive fisheries goal to encourage uptake by industry. The most cited theme (3/7) was the importance of a simple and positive framing that highlights potential benefits to fisheries. Two informants mentioned the value of aligning the nature positive goal with existing terminology that the industry is already familiar with. Finally, two informants suggested that presenting the goal as a step-by-step process, that recognises milestones on the way towards nature positive contributions, could facilitate uptake.

3.3.3 Feasibility of operationalising a fisheries biodiversity metric for real-world use

Respondents with positive views of the suggested metric either cited its similarity to the Defra metric or did not give a reason for their view. Some negative responses questioned whether a metric of this kind would be suitable for the fisheries context due to the interconnected nature of marine systems. Others cited challenges around monitoring and compliance. Lastly, mixed responses were positive about the feasibility of operationalising the metric in theory but mentioned challenges that would have to be addressed first. These included gaps in available information to inform metrics and resistance from industry.

Table 6. *Responses of key-informants relating to their perception of the real-world feasibility of operationalising a fisheries metric of the kind proposed here.*

Responses	Articulated reasoning	Example quotes
Positive responses (48%)	Similarity to Defra metric	*"It's a promising first step that is easy to operationalise which you know is kind of the purpose of the net gain metric"*
	Not expressed	*"Definitely possible to operationalize it for sure"*
Negative responses (14%)	Monitoring and compliance issues	*"It would be quite difficult to withhold fishing licences, for example, until the fishing industry had come up with a plan as to how they were going to demonstrate that through their activities there would be more nature"*
	Marine connectivity	*"I guess whether or not they can be used is whether they fit in a fishery context, and it comes back to can you separate fisheries from everything else that's going on and the marine system is very different to the terrestrial, it's very dynamic and interconnected"*
Mixed responses (38%)	Issues with metrics	*"I think the metric approach is very difficult. I like the idea of it, I guess I'm slightly sceptical as to how it's possible"*
	Information gaps	*"So I think there's another challenge around the level of monitoring of the different indicators and the information that's available to you"*
	Getting uptake	*"You might get opposition from them that it's not their job to restore the oceans."*

3.3.4 Metric feedback from key informants

Key-informants were then asked for their feedback on the metric proposed in this study. Most key-informants (9/12) expressed that they thought the translation of the Defra metric was a useful first step towards achieving nature positive fisheries, or a useful exercise more generally. However, most informants (8/12) also identified potential areas for improvement, some of which overlap with critiques of the Defra metric. These included lack of evidence supporting ecological assumptions of the metric and reservations about offsetting requirements.

I prompted key-informants to suggest additional elements that should be considered alongside the metric when assessing the contributions of fisheries operations towards a nature positive goal.

Higher-level actions, such as collaborations between different marine sectors, were the most frequently suggested (6/12). Other frequently mentioned elements were addressing indirect and cumulative impacts on biodiversity (5/12) and additional indicators for monitoring biodiversity and resilience of marine systems (5/12). Two interviewees also suggested that, considering the broader policy context, including national targets as well as a global target would be important.

When key-informants were asked who they thought might use a metric of this kind, government entities were frequently identified (9/12). Other suggestions included multilateral inter-government bodies (4/12), standards organisations (1/12), and sustainability certification programmes (1/12). As for responses to which type of fishery might use the metric, these ranged from any fishery (3/12) to specifically benthic fisheries because of their direct habitat impacts (2/12), and aspiring leaders in sustainable fishing practices (2/12).

4. Discussion

4.1 First step towards nature positive fisheries

This study is the first to outline how fisheries could address the biodiversity impacts of their direct operations to take their first step towards the nature positive goal and contribute to the mission of the Global Biodiversity Framework. Although existing fisheries management strategies typically aim for sustainable utilisation of fishery resources, global evidence of fishery declines suggests that a different approach is needed to address fisheries' biodiversity impacts (FAO, 2024). Overall, the findings from the case studies suggest that the proposed conceptual framework and biodiversity metric could be adapted and applied to diverse real-world fisheries as their first step on a pathway towards nature positive contributions. Promisingly, this was supported by results from key-informant interviews as most participants expressed that the fisheries metric was a useful first step towards nature positive contributions for fisheries, and most were relatively positive about the feasibility of operationalising the approach. The key-informant interviews also highlighted potential areas for improvement in the proposed approach and perceived challenges that might hinder nature positive outcomes for fisheries in the future. This has implications for future initiatives and research in the area.

4.2 Biodiversity impacts of fisheries do not have a one-size-fits-all solution

The case studies indicated that the path towards nature positive fisheries operations will vary between fisheries. This variability was expected, as I deliberately selected three fisheries with contrasting characteristics to test the framework. Given the immense diversity observed across global fisheries - encompassing differences in impacted biodiversity, gear types, socio-political context, and economic factors - it is evident that a one-size-fits-all management approach is unlikely to deliver desired biodiversity outcomes (Spijkes et al., 2022). Instead, case-specific strategies will be necessary to address specific challenges and opportunities of each fishery. Net outcome approaches are a valuable tool for this as they allow differentiated pathways towards a common goal. For some fisheries, such as the orange roughy and bluefin tuna, aligning with a nature positive ambition may be more challenging due to the size of their biodiversity impacts, and knowledge and innovation gaps. However, for fisheries like the king scallop fishery, which may have considerable impacts but have more readily available compensation measures for the most directly impacted biodiversity, the path towards nature positive operations may be more straightforward. Nonetheless, for all fisheries it will be imperative that there is strict compliance with the mitigation hierarchy, and compensation is only used as a last resort for unavoidable impacts (Maron et al., 2024).

The need to adapt specific management measures to the context of specific case studies was supported by several key-informants pointing to diverse issues associated with the greater connectivity of marine systems compared to terrestrial ones. This observation is supported by existing literature, which suggests that, due to marine connectivity, indirect or cumulative impacts may be particularly dominant in the marine environment (Shumway et al. 2018). This can pose challenges for accurately attributing biodiversity impacts to specific activities or operations. This complexity is further compounded when multiple activities occur in the same or nearby areas, making it difficult to disentangle the causal relationship between a specific action and a biodiversity outcome. To address this issue, several key-informants highlighted the importance of considering interactions between fishery impacts and impacts of other sectors in the same geography alongside the approach proposed in this study. The value of taking interactions between fisheries and other sectors into account is also supported by existing literature (e.g. Tidd et al., 2015). This is likely to become increasingly important as demand for ocean resources expands across multiple sectors, such as European countries seeking a five-fold increase in the capacity of offshore wind farms by 2030 (Wind Europe 2020), which can have interacting effects on fishery impacts.

4.3 Limitations and future directions

4.3.1 Encouraging industry uptake of the nature positive goal

Despite the small sample of fisheries key-informants, themes emerged for framing the nature positive goal to increase uptake by industry. These have implications for future efforts, with the potential to address many of the reservations expressed by key-informants and encourage support within the fishing industry. For instance, relating the nature positive term to existing terms familiar to industry could facilitate greater uptake by making it more relatable and accessible to stakeholders. Similarly, framing the goal as a step-by-step process that acknowledges and rewards fisheries for major advancements along the way could help prevent the goal being viewed as too aspirational. Additionally, presenting the goal in a straightforward and positive manner that emphasises potential benefits to fishing businesses may prevent it from being perceived as yet another regulation to comply with. It would also be worth highlighting the various international regulatory pressures underway in this space and the potential benefits of getting ahead of the curve, including market premiums.

As suggested by key-informants, future initiatives would also benefit from further stakeholder engagement. This could be implemented through interviews or workshops with more diverse groups in the fishing industry, including fishers. Such efforts could provide valuable input on how a nature positive fisheries goal could be operationalised in a way that would be most palatable to stakeholders while still delivering the outcomes desired for biodiversity. The benefit of stakeholder involvement in decision-making is also supported by the literature as being critical for creating fair and salient policies (e.g. Mease et al., 2018).

4.3.2 Real-life case study examples

Expanding on the case studies presented here, the framework and metric would benefit from more real-life case studies. This should be done alongside robust monitoring of outcomes, both for biodiversity and fisheries, to enable ongoing reassessments of the approach and to ensure it delivers the desired outcomes (Hooper et al., 2021). Moreover, as suggested by some key informants, the adoption of the approach by real-world fisheries would provide examples of successful implementation and tangible benefits to other fisheries. In this way, such examples could serve as a catalyst for driving uptake of the approach across the fisheries sector.

4.3.3 Refining the fisheries metric

The proposed fisheries metric could be further improved by addressing research gaps and refining its underlying assumptions. In doing so, the metric could evolve into a more robust tool for managing the biodiversity impacts of fisheries operations. The metric could also have implications more widely, such as for net gain metrics for marine infrastructure developments (e.g. ABPMer, 2019) or as a tool for companies aiming to meet Science-Based Targets for the oceans (SBTN, 2023).

The assumptions and research gaps that should be addressed before real-life implementation can be divided into assumptions shared with other biodiversity metrics and assumptions more specific to the proposed metric. Firstly, like many other biodiversity metrics, the fisheries metric assigns arbitrary weights to inputs, with potential for bias (e.g. Gamarra et al., 2018). To justify these weights, future iterations should involve expert elicitation processes like those conducted for the Defra metric (Natural England, 2023). A more comprehensive sensitivity analysis should also be conducted to test the metric's sensitivity to different weightings (Borgonovo & Plischke, 2016).

Secondly, the fisheries metric has specific ecological assumptions and limitations stemming from data gaps. These assumptions should be empirically tested, and the knowledge gaps addressed. For example, it will be crucial to scientifically validate the assumption that fisheries achieving the maximum MSC score have thereby achieved no net loss, or to update this assumption once new information is available. Research efforts should also investigate the indirect impacts of fisheries operations on ecosystem components and the role of transformative actions for mitigating impacts on biodiversity, with the aim of potentially integrating these factors into the metric. Moreover, further research is needed to improve the reliability of compensation measures and develop novel ones where they are currently lacking. This is particularly important given evidence suggesting that marine compensation efforts have lower success rates compared to terrestrial systems (Shumway et al., 2018).

4.4 Conclusion: One piece of the puzzle for nature positive fisheries

This study presented a first step towards nature positive contributions for fisheries, by focusing on the direct impacts of fisheries operations. Future efforts will need to build upon the proposed approach to consider wider value chains and indirect impacts of fisheries activities (e.g. from fuel use and spread of invasive species on ship hulls). As fisheries progress towards aligning with a nature positive goal, transformative actions will also become increasingly important to deliver the desired outcomes for biodiversity on a societal scale. This is especially pertinent in the marine context, where connectivity may amplify the risk of impact displacement to other areas, undermining positive actions by particular fishing operations. Therefore, it is imperative that fisheries seeking to deliver positive outcomes for biodiversity also expand their actions into driving transformative sector-wide and cross-sectoral collaborations. This wider systems thinking, when founded on robust management of fisheries operations, could help to reconcile blue growth and biodiversity goals and achieve the Global Biodiversity Framework's vision of living in harmony with nature.

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6. Bibliography

ABPmer (2019). *White Paper: Adapting Net Gain for the Marine Environment.* ABPmer. Retrieved from http://www.abpmer.co.uk/buzz/white-paper-adapting-netgain-for-the-marine-environment/

Akçakaya, H. R., et al. (2000). Making Consistent IUCN Classifications under Uncertainty. *Conservation Biology 14* (4): 1001-1013.

Arlidge, W. N., Bull, J. W., Addison, P. F., Burgass, M. J., Gianuca, D., Gorham, T. M., Jacob, C., Shumway, N., Sinclair, S. P., Watson, J. E. M., Wilcox, C., Milner-Gulland, E. J. (2018). A global mitigation hierarchy for nature conservation. *BioScience*, *68*(5), 336-347.

BBOP (Business and Biodiversity Offset Programme) (2012). Standard on biodiversity offsets. Washington, DC: BBOP. Retrieved from https://www.forest-trends.org/wp-content/uploads/imported/BBOP_Standard_on_Biodiversity_Offsets_1_Feb_2013.pdf

Booth, H., Squires, D., & Milner-Gulland, E. J. (2020). The mitigation hierarchy for sharks: A risk-based framework for reconciling trade-offs between shark conservation and fisheries objectives. *Fish and Fisheries*, *21*(2), 269-289.

Booth, H., Milner-Gulland, E. J., & Starkey, M. (2023). Operationalizing transformative change for business in the context of nature positive. *OSF Preprints.* Retrieved from https://doi.org/10.31219/osf.io/vk2hq

Booth, H. (2024). Demystifying corporate nature commitments. Retrieved from https://thebiodiversityconsultancy.com/knowledge-and-resources/demystifying-corporate-nature-commitments-166/

Borges, L., & Revenga, L. (2022). *JC Mackintosh Greenstick, Handline and Fishing Rod Bluefin Tuna Fishery*. Marine Stewardship Council Public Certification Reports. Retrieved from https://fisheries.msc.org/en/fisheries/jc-mackintosh-greenstick-handline-and-fishing-rod-bluefin-tuna-fishery/

Borgonovo, E., & Plischke, E. (2016). Sensitivity analysis: A review of recent advances. *European Journal of Operational Research*, *248*(3), 869-887.

Bull, J. W., Suttle, K. B., Gordon, A., Singh, N. J., & Milner-Gulland, E. J. (2013).

Biodiversity offsets in theory and practice. *Oryx*, *47*(3), 369-380.
Bull, J. W., Taylor, I., Biggs, E., Grub, H. M., Yearley, T., Waters, H., & Milner-Gulland, E. J. (2022). Analysis: the biodiversity footprint of the University of Oxford. *Nature*, *604*(7906), 420-424
Cappell, R., Keus, B., Addison, J. (2018). *SSMO Shetland inshore brown & velvet crab and scallop fishery.* Marine Stewardship Council Public Certification Reports. Retrieved from https://fisheries.msc.org/en/fisheries/ssmo-shetland-inshore-brown-crab-and-scallop/
CBD (2022). The Kunming-Montréal Global Biodiversity Framework. Conference of the Parties to the Convention on Biological Diversity. Retrieved from https://www.cbd.int/doc/c/e6d3/cd1d/daf663719a03902a9b116c34/cop-15-l-25-en.pdf
Davies, R. W. D., Cripps, S. J., Nickson, A., & Porter, G. (2009). Defining and estimating global marine fisheries bycatch. *Marine Policy*, *33*(4), 661-672.
Duffus, N. E., Lewis, O. T., Grenyer, R., Comont, R. F., Goddard, D., Goulson, D., Ollerton, J., Townsend, M. C., Webb, J. A., Wilson, R. I., zu Ermgassen, S. O. (2024). Leveraging Biodiversity Net Gain to address invertebrate declines in England. Ecoevorxiv.
de Silva, G. C., Regan, E. C., Pollard, E. H. B., & Addison, P. F. E. (2019). The evolution of corporate no net loss and net positive impact biodiversity commitments: Understanding appetite and addressing challenges. *Business Strategy and the Environment*, *28*(7), 1481-1495
FAO 2024. *Fishery and Aquaculture Statistics – Yearbook 2021.* FAO Yearbook of Fishery and Aquaculture Statistics. Rome. Retrieved from https://doi.org/10.4060/cc9523en
Folke, C., Österblom, H., Jouffray, J. B., Lambin, E. F., Adger, W. N., Scheffer, M., Crona, B. I., Nyström, M. N., Levin, S. A., Carpenter, S. R., Anderies, J. M., Chapin III, S., Crépin, A., Dauriach, A., Galaz, V., Gordon, L. J., Kautsky, N., Walker, B. H., Watson, J. R., Wilen, J., Zeeuw, A. (2019). Transnational corporations and the challenge of biosphere stewardship. *Nature ecology & evolution*, *3*(10), 1396-1403.
Gamarra, M. J. C., Lassoie, J. P., & Milder, J. (2018). Accounting for no net loss: A critical assessment of biodiversity offsetting metrics and methods. *Journal of environmental management*, *220*, 36-43.
Gardner, T. A., Benzie, M., Börner, J., Dawkins, E., Fick, S., Garrett, R., Godar, J., Grimard, A., Lake, S., Larsen, R. K., Mardas, N., McDermott, C. L., Meyfroidt, P., Osbeck, M., Persson, M., Sembras, T., Suavet, C., Strassburg, B., Trevisan, A., West, C., Wolvekamp, P. (2019). Transparency and sustainability in global commodity supply chains. *World Development*, *121*, 163-177.
Gupta, T., Booth, H., Arlidge, W., Rao, C., Manoharakrishnan, M., Namboothri, N., Shanker, K., Milner-Gulland, E. J. (2020). Mitigation of elasmobranch bycatch in trawlers: a case study in Indian fisheries. *Frontiers in Marine Science*, *7*, 571.
Hawkins, Isobel. 2022. Assessing the Performance of DEFRA's Biodiversity Metric. Master thesis, University of Oxford. Retrieved from http:// iccsnew.wpengine.com/wp-content/uploads/2023/08/Dissertation-final_2.pdf.

Hilborn, R., Walters, C. J., & Ludwig, D. (1995). Sustainable exploitation of renewable resources. *Annual Review of Ecology and Systematics*, *26*(1), 45-67.

Hooper, T., Austen, M., & Lannin, A. (2021). Developing policy and practice for marine net gain. *Journal of Environmental Management*, *277*, 111387.

Jones, J. P., Collen, B. E. N., Atkinson, G., Baxter, P. W., Bubb, P., Illian, J. B., Katzner, T. E., Keane, A., Loh, J., McDonald-Madden, E., Nicholson, E., Pereira, H. M., Possingham, H. P., Pullin, A. S., Rodrigues, A. S. L., Ruiz-Gutierrez, V., Sommerville, M., Milner-Gulland, E. J. (2011). The why, what, and how of global biodiversity indicators beyond the 2010 target. *Conservation Biology*, *25*(3), 450-457.

Lambin, E. F., Gibbs, H. K., Heilmayr, R., Carlson, K. M., Fleck, L. C., Garrett, R. D., de Waroux, Y. P., McDermott, C. K., McLaughlin, D., Newton, P., Nolte, C., Pacheco, P., Rausch, L., Streck, C., Thorlaksson, T., Walker, N. F. (2018). The role of supply-chain initiatives in reducing deforestation. *Nature Climate Change*, *8*(2), 109-116.

Locke, H., Rockström, J., Bakker, P., Bapna, M., Gough, M., Hilty, J., Lambertini, M., Morris, J., Polman, P., Rodrigues, C. M., Samper, C., Sanjayan, M., Zabey, E., Zurita, P. (2021). A nature-positive world: The global goal for nature. *WBCSD*. Retrieved from https://www.wbcsd.org/download/file/11960

Chuenpagdee, R., Jentoft, S. (2019). Transdisciplinarity for small-scale fisheries governance. *MARE Publication Series. Springer International Publishing.* Retrieved from https://link.springer.com/content/pdf/10.1007/978-3-319-94938-3.pdf

Maron, M., Brownlie, S., Bull, J. W., Evans, M. C., von Hase, A., Quétier, F., Watson, J. E. M., & Gordon, A. (2018). The many meanings of no net loss in environmental policy. *Nature Sustainability*, *1*(1), 19-27.

Maron, M., Quétier, F., Sarmiento, M., Ten Kate, K., Evans, M. C., Bull, J. W., Jones, J. P. G., zu Ermgassen, S. O. S. E., Milner-Gulland, E.J., Brownlie, S., Treweek, J., von Hase, A. (2024). 'Nature positive' must incorporate, not undermine, the mitigation hierarchy. *Nature Ecology & Evolution*, *8*(1), 14-17.

Mease, L. A., Erickson, A., & Hicks, C. (2018). Engagement takes a (fishing) village to manage a resource: Principles and practice of effective stakeholder engagement. *Journal of environmental management*, *212*, 248-257.

MSC (2023). *The MSC fisheries standard version 3.* Marine Stewardship Council. Retrieved from https://www.msc.org/standards-and-certification/fisheries-standard/version-3

Milner-Gulland, E. J., Addison, P., Arlidge, W. N., Baker, J., Booth, H., Brooks, T., Bull, J. W., Burgass, M. J., Ekstrom, J., zu Ermgassen, S. O. S. E., Fleming, L. V., Grub, von Hase, A., Hoffman, M., Hutton, J., Juffe-Bignoli, D., ten Kate, K., Kiesecker, J., Kumpel, N. F., Maron, M., Newing, H.S., Ole-Moiyoi, K., Sinclair, C., Sinclair, S., Starkey, M., Stuart, S. N., Tayleur, C., Watson, J. E. (2021). Four steps for the Earth: mainstreaming the post-2020 global biodiversity framework. *One Earth*, *4*(1), 75-87.

Milner-Gulland, E. J., Garcia, S., Arlidge, W., Bull, J., Charles, A., Dagorn, L., Fordham, S., Zivin, J. G., Hall, M., Shrader, J., Vestergaard, N., Wilcox, C., Squires, D. (2018). Translating the terrestrial mitigation hierarchy to marine megafauna by-catch. *Fish and Fisheries*, *19*(3), 547-561.

Naito, R., Zhao, J., & Chan, K. M. (2022). An integrative framework for transformative social change: a case in global wildlife trade. *Sustainability Science*, *17*(1), 171-189.

Natural England, 2023. *The Biodiversity Metric 4.0* - JP039. Retrieved from https://publications.naturalengland.org.uk/publication/6049804846366720 661

Punt, A., Trumble, R. J., Stern-Prilot, A. (2022) *New Zealand Orange roughy.* Marine Stewardship Council Public Certification Reports. Retrieved from https://fisheries.msc.org/en/fisheries/new-zealand-orange-roughy/

Shumway, N., Watson, J. E., Saunders, M. I., & Maron, M. (2018). The risks and opportunities of translating terrestrial biodiversity offsets to the marine realm. *BioScience*, *68*(2), 125-133.

Science Based Targets Network. (2023). *Oceans*. Retrieved from https://sciencebasedtargetsnetwork.org/our-mission/issue-hubs/ocean/

Spijkers, J., Mackay, M., Turner, J., McNeill, A., Travaille, K., & Wilcox, C. (2023). Diversity of global fisheries governance: Types and contexts. *Fish and Fisheries*, *24*(1), 111-125.

Squires, D. and S. Garcia (2018). The least-cost biodiversity impact mitigation hierarchy with a focus on marine fisheries and bycatch issues. *Conserv Biol* 32(5): 989-997.

Tidd, A. N., et al. (2015). Fishing for space: fine-scale multi-sector maritime activities influence fisher location choice. *PLoS One 10*(1): e0116335.

Tursi, A., Maiorano, P., Sion, L., D'Onghia, G. (2015). Fishery resources: between ecology and economy. *Rendiconti Lincei*, *26*, 73-79.

UN (2022). *Incentivising Sustainable Fisheries through certification* United Nations. Retrieved from https://sdgs.un.org/partnerships/incentivising-sustainable-fisheries-through-certification-0

Wind Europe. (2020). *Offshore Wind in Europe. Key trends and statistics 2019*. Retrieved from https://windeurope.org/about-wind/statistics/offshore/european-offshore-windindustry-key-trends-statistics-2019/

Williams, P. A., Simpson, N. P., Totin, E., North, M. A., & Trisos, C. H. (2021). Feasibility assessment of climate change adaptation options across Africa: an evidence-based review. *Environmental Research Letters*, *16*(7), 073004.

zu Ermgassen, S. O. S. E., Howard, M., Bennun, L., Addison, P. F., Bull, J. W., Loveridge, R., Polland, E., Starkey, M. (2022). Are corporate biodiversity commitments consistent with delivering 'nature-positive' outcomes? A review of 'nature-positive' definitions, company progress and challenges. *Journal of Cleaner Production*, *379*, 134798.

zu Ermgassen, S. O., Marsh, S., Ryland, K., Church, E., Marsh, R., & Bull, J. W. (2021).

Exploring the ecological outcomes of mandatory biodiversity net gain using evidence from early-adopter jurisdictions in England. *Conservation Letters*, *14*(6), e12820.

7. Management Report

Initial planning and conceptualisation (September-October)

I first met with my supervisors at the end of September to discuss the project's direction as the project's scope and focus were not fully developed despite having written up a research proposal that spring. This can be attributed to the lack of previous research for fisheries in this area to use as a reference for organising my project and uncertainties regarding the data I would have access to. By third week of Michaelmas term, I had decided on the focus and appropriate scope of my project, based on my reading, planning, and discussions with my supervisors during 30-minute fortnightly meetings.

Literature review and conceptual framework development (October-November)

I spent the next three weeks of Michaelmas term conducting my literature review to inform the development of the conceptual framework. Alongside the review I started going weekly to the office of the Marine Stewardship Council (MSC) in London to meet with my co-supervisor when he was available, interview and engage in informal discussions with other MSC staff for my project. By mid-December I had developed a first draft of the conceptual framework based on the information gathered.

Development of the metric and case studies (December-April)

During the Christmas vac I did a few scenario planning type exercises involving researching a few MSC-certified fisheries and trying out working through the framework for each one to test and refine it. This exercise also helped me think about what kind of approach and methods I could use for the formal fishery case studies in my project, in particular, what methods to use for the technical assessment. During the first three weeks of January, I experimented with various potential methodologies for the technical assessment, eventually deciding to try to adapt the 'Defra biodiversity metric' for this purpose.

Alongside adapting the metric for fisheries, during Hilary term I identified three fisheries as potential interesting case studies for my project and discussed these with my supervisors. These were different fisheries to the ones I used for the scenario planning exercise, except for the tuna fishery as I decided it would make a good case study. I worked through the framework for each of these three case studies and used them to trial the metric approach. This helped me refine the metric but also meant that I ended up repeating the technical assessment for each fishery several times. The final version of the fisheries metric was ready approximately two weeks into the Easter vacation.

Interviews and analysis (January-April)

In late January, we decided that I would have time to conduct interviews to complement the other parts of my project. This was something I had expressed an interest in doing during Michaelmas term but at that stage it had not been clear whether I would have time for them. I completed my CUREC application for the interviews right away, on the 31st of January, and my application got approved on the 4th of March. As the aim of the interviews was only to gain a preliminary views from key informants given the short time available, I chose only a few particularly knowledgeable experts to contact. Most of them got back to me quickly which allowed me to finish the interviews by the 2nd of April. As time was running short, I focused only on the interview analysis for the next week and managed to finish it by the 9th of April.

Write up of project (April-May)

After completing the interview analysis and finalisation of the framework and case studies by the 9th of April, I transitioned into writing up the project findings and making a few extra figures. As I had already made write-up plans for the sections of the paper by the time I started writing, I was able to write it up relatively quickly and finished my first draft on the 18th of April.

8. Appendix

Appendix I: Review of the Defra metric

Metric	Cost-effectiveness	Coverage of diverse taxonomic groups	Reliability of information about biodiversity	Applicability at multiple scales	Allow frequent reporting	Meaningfulness to the public
Defra Biodiversity metric 4.0	Requires a 30-year management and monitoring plan for each development but is relatively flexible in terms of monitoring methods. Thus, costs of monitoring indicators could be compared with expected values of the information the measures provided, as suggested by Jones et al. (2011) for cost effectiveness.	The metric has been criticised for overlooking invertebrates (Duffus et al., 2024), however, this could be addressed if adapted for the marine context in the future by e.g. considering connectivity, redefining habitat condition, and providing standardised guidance for surveys that include invertebrate surveys, where relevant (Duffus et al., 2024).	The metric requires information from relatively diverse sources, including expert elicitations and field surveys based on key indicators, which suggests it is difficult to manipulate. Additionally, in the marine context, the metric should consider species as well as habitat which would help ensure the metric reliably reflects trends in underlying biodiversity components.	The metric is being adapted for use in other countries (e.g. Denmark; Greenwood & Eve, 2021) which suggests it is informative at multiple scales, including at the global scale as well as nationally and sub-nationally, as suggested as desirable by Jones et al. (2011).	There is no requirement in place for how often the indicator values being used for monitoring should be reported, but in theory it could be done annually (provided funding is available), as suggested by Jones et al. (2011) for cases where indicators are used to audit management actions.	The Biodiversity Net Gain policy the metric is being used for in the UK has attracted quite widespread interest, including from the media, and the metric can be explained in a way that is understandable to non-experts so meets the criteria outlined by Jones et al. (2011) relatively well.

Table S1. The Defra Biodiversity Metric reviewed against the key criteria outlined by Jones et al., 2011for desirable characteristics of biodiversity indicators relevant to the purposes of the metric for fisheries.

Appendix II: Metric equations

1. Habitat – calculating area habitat-based units (AHBUs)

Equation 1: Pre-impact (t_0) baseline biodiversity units

t_0 *Baseline AHBU* $= (A^{t0} \times D^{t0} \times C^{t0}) \times (SS^{t0})$

Equation 2: Post-management intervention (t_1) biodiversity units for habitat:

t_1 *Post management intervention AHBU* $= \{[A^{t1} \times D^{t1} \times C^{t1}] \times [R_T] \times [SS^{t1}]\}$

Equation 3: Biodiversity units required for 10% AHBU Net Gain:

10% NG AHBU $= \{([A^{t1} \times D^{t1} \times C^{t1}] \times [SS^{t1}]) \times 0.1\}$

Equation 4: Biodiversity units required for AHBU NNL:

Units required for AHBU NNL $= \{[A^{t1} \times D^{t1} \times C^{t1}] \times [SS^{t1}]\}$

Equation 5: Post-impact (t_1) biodiversity units for habitat creation:

t_1 *Creation AHBU* $= [\{A^{t1} \times D^{t1} \times C^{t1}\} \times \{R_D \times R_T \times R_{EU}\} \times \{SS^{t1}\}]$

Equation 6: Area habitat biodiversity unit change on-site:

Onsite AHBU change = ({t_1 Creation AHBU on-site + t_1 Post management intervention AHBU} – {Units required for AHBU NNL})

Equation 7: Area habitat biodiversity unit change off-site:

Offsite AHBU change = [({ t_1 Creation AHBU off-site + t_1 Post management intervention AHBU} - {Units required for AHBU NNL}) × R_{OS}]

Equation 8: Total area habitat biodiversity unit change (total)

Total AHBU change = Onsite AHBU change + Offsite AHBU change

Equation 9: Total habitat biodiversity units missing for 10% NG:

Total AHBU missing for 10% NG = {10% NG AHBU} – {Total AHBU change}

A	Area of habitat (hectares)	R_D	Difficulty (a risk factor)
C	Condition	R_T	Time to target condition (a risk factor)
D	Distinctiveness	R_{OS}	Spatial risk (off-site risk factor)
SS	Strategic Significance	R_{EU}	Uncertainties (a risk factor)
T_0	Pre-intervention (baseline)	T_1	Post-intervention

2. Species – calculating species-based units (SBUs)

Equation 1: Pre-impact (t_0) baseline biodiversity units:

$$t_0 \text{ Baseline SBU} = (D^{t0} \times C^{t0} \times Ca^{t0}) \times (SS^{t0})$$

Equation 2: Post-management intervention (t_1) biodiversity units for species:

$$t_1 \text{ Post management intervention SBU} = \{[D^{t1} \times C^{t1}] \times [R_T] \times [SS^{t1}]\}$$

Equation 3: Biodiversity units required for 10% SBU Net Gain:

$$10\% \text{ NG SBU} = \{([D^{t1} \times C^{t1}] \times [SS^{t0}]) \times 0.1\}$$

Equation 4: Biodiversity units required for SBU NNL:

$$\text{Units required for SBU NNL} = \{[A^{t1} \times D^{t1} \times C^{t1}] \times [SS^{t1}]\}$$

Equation 5: Post-impact (t_1) biodiversity units for species through compensation:

$$t_1 \text{ Onsite Compensation SBU} = \{[D^{t1} \times A^{t1} \times AvD \times C^{t1}] \times \{R_D \times R_T \times R_{EU}\} \times [SS^{t1}]\}$$

Equation 6: Species biodiversity unit change on-site:

$$\text{Onsite SBU change} = \{t_1 \text{ Onsite Compensation SBU} + t_1 \text{ Post management intervention SBU}\} - \{\text{Units required for SBU NNL}\}$$

Equation 7: Species biodiversity unit change off-site:

$$\text{Offsite SBU change} = [\{t_1 \text{ Offsite Compensation SBU} + t_1 \text{ Post management intervention SBU}\} - \{\text{Units required for SBU NNL}\} \times R_{OS}]$$

Equation 8: Total area habitat biodiversity unit change (total)

$$\text{Total SBU change} = \text{Onsite SBU change} + \text{Offsite SBU change}$$

Equation 9: Total species biodiversity units missing for 10% NG:

$$\text{SBU missing for 10\% NG} = \{10\% \text{ NG SBU}\} - \{\text{Total SBU change}\}$$

D	Distinctiveness	AvD =	Average density of species/ha of habitat
C	Condition	R_T	Time to target condition (a risk factor
Ca	Catch [t]	R_D	Difficulty (a risk factor)
SS	Strategic Significance	R_{OS}	Spatial risk (off-site risk factor)
T_0	Pre-intervention (baseline)	R_{EU}	Uncertainties (a risk factor)
T_1	Post-intervention		

Appendix III: Metric criteria and inputs

Baseline calculations

Species

- Distinctiveness: Based on the IUCN Red List and CITES Appendix I which ranges from least concern to extinct.
    - Following the scoring range of the Defra metric, the score ranges from least concern (0) to critically endangered (8) based on the IUCN Red List categories (excluding the 'Extinct in the wild' and 'Extinct' categories).

- If a species (or species group) is listed on CITES Appendix I then it will receive the 'Endangered' score because the criteria for CITES Appendix I roughly aligns with the Endangered listing on the IUCN Red List

- Catch [t]: Based on the TAC in tonnes reported from the MSC assessment. This should be from the baseline year (2020) where possible, otherwise the nearest estimate.
- Condition for target stock: Based on MSC's overall score for Principle 1 which includes a score for outcome (stock status & rebuilding) and management (harvest strategy, harvest control rules & tools, information & monitoring, and assessment of stock status)
  - Following the scoring range of the Defra metric, the score ranges from okay (1) to excellent (3) based on whether the MSC score for Principle 1 meets 60-80-100.
  - Note in the Defra metric the score is from poor (1) - good (3) with 5 levels
- Condition for ETP and other bycatch species: Based on MSC's score for Principle 2 performance indicators relating to the primary and secondary species (including outcome, management and information)
  - Following the scoring range of the Defra metric, the score ranges from okay (1) to excellent (3) based on whether the MSC score for the primary/secondary species outcome, management and information meets 60-80-100
- Strategic significance: Based on whether the species has been identified by the MSC or other literature as a keystone or foundation species. Keystone species refers to a species that has a disproportionately large impact on the structure of its ecological community relative to their abundance and foundation species refers to species that play a key role in creating and maintaining a habitat for other species (Power, 1996).
  - The score ranges from keystone or foundation species (3) to not a keystone or foundation species (1.5). These values are higher than in the Defra metric to try to capture some of the ecosystem effects of the fishery's operations (in particular, the impacts from catches on other trophic levels), and not just direct impacts to the species.

Habitat

- Distinctiveness: Based on whether the habitat type is (1) listed as threatened and/or in decline at a regional or national scale (e.g. by OSPAR, UK BAP habitat, Priority Marine Feature); (2) listed as threatened and/or in decline at an international scale (e.g. as a VME or PSSA); and (3) estimated species richness of the habitat type in the area.
  - This is roughly based on the criteria used in the Defra metric to assess habitat distinctiveness, except it does not consider to what extent the habitat supports species rarely found in other habitats (Natural England, 2023), as that is already captured in a way by the species metric, and neither is 'current protection of the habitat' because the information for what proportions of each habitat type is protected is generally not available in the marine context

    - Following the scoring range of the Defra metric, the score ranges from Very Low (0) to Very High (8). This is based on whether it meets the criteria for regional or national rarity (2 points if it does, 0 points if not), international rarity (2 points if it does, 0 points if not), and species richness (4 points for habitats considered high in biodiversity at a regional or national scale; 2 point for medium biodiversity; and 0 points for severely degraded habitats or low biodiversity)
- Area [ha]: Size of the area of habitat impacted
- Condition: Based on MSC's score for performance indicators relating to habitat (includes ones on outcome, management and information)
    - Following the scoring range of the Defra metric, the score ranges from okay (1) to excellent (3) based on whether the MSC score for habitat outcome, management and information 60-80-100
- Strategic significance: Based on whether the area has been formally identified as important to conservation or is in a priority area for habitat creation/enhancement, i.e. whether it is within a protected area (MPA, BPA, SCA or equivalent) or a buffer zone.
    - The score ranges from high (1.15) for habitats that are within areas formally identified as important to conservation (PA), medium (1.1) for habitats that are where location is ecologically desirable but not officially declared so in policy (candidate PAs and habitats adjacent to PAs or buffer zones), and low (1) for habitats that are within areas not identified as important to conservation (do not meet the above criteria)
    - The most recent version of the Defra metric does not include a possible medium value, but older versions of the metric did

Post management intervention calculation

Species

- The scoring of distinctiveness and strategic significance follow the same conditions as in the baseline calculation.
- Condition: if the fishery implements the management measures and improvements required to achieve the maximum score against the MSC Fisheries Standard for stock status and assessment/information, and additional precautionary measures where relevant, the final condition score will be excellent (3).
- Catch: to account for any decreases in catches and that it should increase the score as it decreases the impact on biodiversity, the calculation for score in the post-management intervention status score includes:
    - Current catch
    - Baseline catch (this is what the NNL score is based on)
    - Difference between current catch and baseline catch (current catch/baseline catch)

    - Final catch score: considers the above factors in a way that if there was e.g. a 10% decrease in catches, the score for catches is 10% higher than the baseline score, but if catches remain the same it is unchanged
- Temporal multiplier: This is to account for the time required for the condition of the species to improve following changes in management strategy. The temporal multiplier is divided into:
    - Standard recovery time (years): Species' generation time is used as a proxy.
        - If the difference between the baseline ecological condition score and the post-intervention ecological condition score is 1, the value for the generation time of species is used
        - If the difference between the baseline ecological condition score and the post-intervention ecological condition score is 1.5, the value for the generation time of species times 1.5 is used etc.
    - Delay in starting habitat creation (years): Accounts for delays in improving the management strategy by increasing the time to recovery proportionate to the length of delay. The metrics allows 1-5 years.
    - Final time to target condition (years): The sum of standard recovery time and delay in starting habitat creation. Following the Defra metric, if the final time exceeds 30 years, the 30+ years multiplier is applied
    - Final time to target multiplier: Following the Defra metric, a standard discount rate of 3.5% is applied. The resulting multiplier ranges from 1.000 (for 0 years) to 0.320 (for 30+ years)

Habitat

- The scoring of distinctiveness, area and strategic significance follow the same principles they did in the baseline calculation.
- Condition: if the fishery implements the management measures and improvements required to achieve the maximum score against the MSC Fisheries Standard for habitat condition and information, and additional precautionary measures where relevant, the final condition score will be excellent (3).
- Temporal multiplier: This is to account for the time required for the condition of the habitat to improve following changes in management strategy. The temporal multiplier is divided into:
    - Standard time to target condition (years): Rough estimate based on available literature. The value varies depending on habitat type and condition pre-management intervention
    - Delay in starting habitat creation (years): Accounts for delays in improving the management strategy by increasing the time to recovery proportionate to the length of delay. The metric allows 1-5 years.
    - Final time to target condition (years): The sum of standard recovery time and delay in starting habitat creation. Following the Defra metric, if the final time exceeds 30 years, the 30+ years multiplier is applied

    - Final time to target multiplier: Following the Defra metric, a standard discount rate of 3.5% is applied. The resulting multiplier ranges from 1.000 (for 0 years) to 0.320 (for 30+ years)

<u>Compensation calculation</u>

Habitat Creation

- The scoring of distinctiveness, area and strategic significance follow the same principles they did in the baseline calculation.
- <u>Overall condition:</u> Combined score for target condition and information of the created habitat
- <u>Temporal multiplier:</u> This is to account for the time required for the habitat being restored to reach target condition, following the Defra metric. The multiplier is divided into:
    - Standard time to target condition (years): Rough estimate based on available literature. This value varies depending on the habitat type, target condition
    - Habitat created in advance (years): This recognises the reduced delivery risk and reduces the time to target condition by the number of years since habitat creation or enhancement began
    - Delay in starting habitat creation (years): This accounts for delays in habitat works by increasing the time to target condition value proportionate to the length of delay. The metric allows 1-5 years.
    - Final time to target condition (years): The sum of standard recovery time and delay in starting habitat creation. Following the Defra metric, if the final time exceeds 30 years, the 30+ years multiplier is applied
    - Final time to target multiplier score: Following the Defra metric, a standard discount rate of 3.5% is applied. The resulting multiplier ranges from 1.000 (for 0 years) to 0.320 (for 30+ years)
- <u>Difficulty multiplier:</u> This is to account for the variable difficulty of habitat creation, depending on the habitat type, following the Defra metric. The multiplier is divided into:
    - Standard difficulty of creation: The Defra metric considers several factors for this, but the general principle it follows is that the category of the habitat equals its distinctiveness category. The only exception is that both very low and low distinctiveness habitats get classified as low for standard difficulty of creation, following what the Defra metric seems to do
    - Difficulty multiplier score: The resulting multiplier ranges from low (1) for habitats of very low and low standard difficulty of creation to very high (0.1) for habitats of very high standard difficulty of creation
- <u>Spatial risk multiplier:</u> This accounts for the relationship between the location of biodiversity loss and habitat compensation. This is only relevant for interventions that do not occur within the impacted site, that is for off-site compensation. The multiplier is divided into:

- Spatial risk category: Following the Defra metric there are three possible categories: within, neighbouring and outside. For this metric the criteria for intertidal habitats in the Defra metric is adapted so that (1) within refers to compensation inside the same Marine Plan Area, or deemed sufficiently local, to site of biodiversity loss and gets a score of 1 ; (2) neighbouring refers to compensation outside the same Marine Plan Area but in neighbouring one and gets a score of 0.75; and (3) outside refers to compensation outside Marine Plan Area of impact site and beyond neighbouring ones and gets a score of 0.5
- Spatial risk multiplier score: The resulting multiplier ranges from 1 (for within) to 0.5 (for outside)

Habitat enhancement

- The scoring of distinctiveness, area, strategic significance and the other three multipliers follow the same principles they did in the habitat creation calculation
- <u>Post-enhancement (t1) values:</u> These are the target values for overall condition, area, and distinctiveness of the habitat subject to enhancement, after it has been enhanced
    - Note, can only trade up for distinctiveness, condition, and strategic significance.
- <u>Pre-enhancement (t0 values):</u> These are the target values for overall condition, area, and distinctiveness of the habitat subject to enhancement, after it has been enhanced

Species compensation (through habitat creation/enhancement)

- <u>Habitat type:</u> This refers to the habitat type being created/enhanced for the species
- <u>Species distinctiveness, condition and strategic significance:</u> These relate to the impacted species and follow the same conditions as species distinctiveness in the baseline calculation for species
- <u>Area</u> [ha]: Size of the area being created/enhanced for the species
- <u>Average density of species per ha within the habitat:</u> This is estimated based on available literature for average densities of the species under good conditions for that habitat type
- <u>Species condition:</u> Condition and assessment of condition of the impacted species, following the same conditions as species distinctiveness in the baseline calculations for species
- <u>Multipliers:</u> The same other three multipliers are applied here as for habitat creation/compensation

Appendix IV: Sensitivity analysis outputs

1. Bluefin tuna fishery

<u>Output of the three simulations</u> (includes best estimates and feasible ranges (where relevant) for each score)

Baseline score: 1195

Species post management intervention score: 700 (feasible range: 676-752)

Total units required for NNL for species: 1195

Total units required for 10% Net Gain of species: 119.5

Total units missing for 10% Net Gain of species: 614 (feasible range: 563-638)

2. Orange roughy fishery

Output of the three simulations (includes best estimates and feasible ranges (where relevant) for each score)

Species:

Total species baseline score: 25496 (feasible range: 12765-38261)

Species post management intervention score: 12378 (feasible range: 6226-18565)

Total units required for NNL for species: 38242 (feasible range: 19147-57391)

Total units required for 10% Net Gain of species: 3824 (feasible range: 1915-5739)

Total species units missing for 10% Net Gain of species: 29691 (feasible range: 14835-44565)

Habitats:

Total habitat baseline score: 3556714 (feasible range: 2405673-3556714)

Habitat post management intervention score: 583836 (feasible range: 450287-699084)

Total units required for NNL of habitats: 5335070 (feasible range: 3608510-5335070)

Total units required for 10% Net Gain of habitats: 533507 (feasible range: 360851-533507)

Total habitat units missing for 10% Net Gain of habitats: 5284741 (feasible range: 2067441-5418291)

3. King scallop fishery

Output of the three simulations (includes best estimates and feasible ranges (where relevant) for each score)

Baseline & post management intervention scores:

Species:

Total species baseline score: 9173 (feasible range: 5782-18558)

Species post management intervention score: 11801 (feasible range: 7933-22595)

Total units required for NNL of species: 13760 (feasible range 8672-27837)

Total units required for 10% NG of species: 1376 (feasible range: 867-2783)

Total units missing for NNL of species: 1959 (feasible range: 740-5242)

Habitats:

Total habitat baseline score: 539 (feasible range: 539-1077)

Habitat post management intervention score: 745 (feasible range: 772-1387)

Total units required for NNL of habitats: 808 (feasible range: 808-1616)

Total units required for 10% Net Gain of habitats: 81 (feasible range: 81-162)
Units missing for NNL of habitats: 64 (feasible range: 37-230)

Offsetting option 1: Habitat creation on-site of 280 ha (feasible range: 13-2250ha) of good condition gravel habitat
Total units missing for 10% Net Gain pf species: 4 extra species units (feasible range: -7026 units missing - 1729 extra units)
Total units missing for 10% Net Gain of habitats: 275 extra habitat units (feasible range: 129 units extra - 334 extra units)
Offsetting option 2: Habitat creation in a 'within' off-site location of 765 ha (feasible range: 330-1400ha) of good condition maerl bed habitat
Total units missing for 10% Net Gain of species: 1 extra species unit (feasible range: 3543 units missing - 2131 extra units)
Total units missing for 10% Net Gain of habitats: 433 extra habitat units (feasible range: 59 units extra - 572 extra units)
Offsetting option 3: Habitat creation in a 'neighbouring' off-site location of 850ha (feasible range: 380-1510ha) good condition maerl bed habitat and 800 (feasible range:200-1250ha) good condition horse mussel beds
Total units missing for 10% Net Gain of species: 13 extra species units (feasible range: 2928 units missing - 1859 extra units)
Total units missing for 10% Net Gain of habitats: 894 extra habitat units (feasible range: 494 units extra - 1048 extra units)

Appendix V: Interview questions

A. Interview questions from interview with biodiversity net gain experts

General questions

1) What sector do you work in (academic, government, industry etc.)?
2) What is your role in your current job?

Questions on the nature positive goal

3) Were you familiar with the nature positive goal before I contacted you to do an interview?
4) Do you think the current management of the biodiversity impacts of fisheries is enough to ensure that fisheries are contributing towards the positive global goal? Please elaborate on your answer.

Questions on the proposed metric for fisheries

5) Based on this information, what is your initial feeling about this suggested extension of the UK government-prescribed metric to the fisheries context? Do you think a metric of this kind could

be adapted for use by fisheries managers and operationalised in the real world? If not, why not?

6) Are there any additional factors that you think should be included in the metric or any currently used that you think should be excluded? If so, why?
7) Do you have any other suggestions for how the metric could be improved? Are there any changes that you think would make it more likely to deliver positive results for biodiversity?
8) Do you have any thoughts about other elements that should be taken into account alongside the metric, when assessing the contributions of fisheries towards a NP goal? Thinking just about the impacts of fishing operations on the ecosystem and target species, rather than the whole operations of a fishing business.
9) Who do you think might use a tool like this? Which types of fishery, and why? Do you think this is something a government like the UK might consider using?
10) Any further comments on whether this is a useful exercise, and any pitfalls, challenges, or opportunities you could envisage?

B. Interview questions from interview with fisheries experts

General questions

1) What sector do you work in (academic, government, industry, NGO etc.)?
2) What is your role in your current job?

Questions on the nature positive goal

3) Were you familiar with the nature positive goal before I contacted you to do an interview?
4) Is nature positive fisheries a concept that resonates with you? How do you think it is generally likely to be perceived by fisheries managers or others working in the fishing industry?
5) Do you think the current management of the biodiversity impacts of fisheries is enough to ensure that fisheries are contributing towards the nature positive global goal? Please elaborate on your answer?
6) How do you think that the nature positive goal could be operationalised in the context of fisheries? Do you think it would primarily be driven by voluntary actions from industry, such as seeking MSC certification, or do you think regulatory action from governments will be needed?

Questions on proposed metric for fisheries

7) Were you familiar with the nature positive goal before I contacted you to do an interview?
8) Is nature positive fisheries a concept that resonates with you? How do you think it is generally likely to be perceived by fisheries managers or others working in the fishing industry?
9) Do you think the current management of the biodiversity impacts of fisheries is enough to ensure that fisheries are contributing towards the nature positive global goal? Please elaborate on your answer?

10) How do you think that the nature positive goal could be operationalised in the context of fisheries? Do you think it would primarily be driven by voluntary actions from industry, such as seeking MSC certification, or do you think regulatory action from governments will be needed?

Appendix VI: Codebooks for the interview analysis

Deductive codebook

Name	Description
1) Metric feedback	Feedback from key-informants on the suggested metric
2) Operationalising the metric	Comments related to operationalising the metric
A) Challenges	Potential challenges for operationalising the metric in the real-world
B) Feasibility of real-world adaptation	Participant's opinion of whether a metric of this kind could be adapted for use in the real world
C) Potential users of the metric	Bodies that might use or prescribe a metric of this kind
3) Operationalising the nature positive fisheries goal	Potential challenges for operationalising the nature positive goal for fisheries in the real-world
A) Challenges of operationalisation	Potential challenges of operationalising the nature positive fisheries goal
B) Drivers of operationalisation	Potential driving forces of operationalising the nature positive goal for fisheries
4) Perception of the nature positive fisheries goal	Perception of the nature positive goal for fisheries
A) Adequacy of current management to meet the nature positive goal	Comments on whether current management of fisheries is enough to ensure that fisheries are contributing towards the goal
B) Perception of fisheries expert participant	The perception participants have of the nature positive goal for fisheries
C) Predicted perception of other stakeholders	Participants' prediction for how industry might perceive a nature positive fisheries goal

Final codebook (includes inductive codes)

Name	Description
1) Metric feedback	Feedback from key-informants on the suggested scoring approach
A) Additional elements to consider	Suggested additional elements to consider alongside metric
Broader conservation context	Comments suggesting that the broader conservation context should be considered alongside the metric
Higher-level actions	Comments suggesting that higher-level actions should be considered alongside the metric
Local indirect and cumulative issues	Comments suggesting that local indirect and cumulative issues should be considered alongside the metric

Name	Description
Other indicators	Comments suggesting that some other indicators should be considered alongside the metric
B) Positive feedback	Positive feedback from experts on the proposed approach
Useful	Comments suggesting that it is generally useful
Useful first step for fisheries	Comments suggesting that it is a useful first step for fisheries in the nature positive context
C) Suggested areas for improvement	Suggested areas for improvement of the approach
Does not capture greater ecosystem impacts	Comments pointing to that the metric could be improved by capturing greater ecosystem impacts
Ecological assumptions	Comments pointing to that the ecological assumptions of the metric represent a limitation
Metric sensitivity	Comments pointing to that the sensitivity of the metric could be improved
Offsetting component	Comments pointing to that the offsetting component of the metric could be improved
2) Operationalising a metric of this kind	Comments relating to operationalising a metric of the kind proposed
A) Feasibility of real-world adaptation of a metric of this kind	Comments relating to whether participants think a metric of this kind could be adapted for use in the real world
Mixed comments	Responses conveying a positive sentiment towards the feasibility of real-world adaptation in theory but also point to some reservations
Getting uptake	Mixed comment, mentions getting uptake of the metric may be a challenge to operationalisation
Information gaps	Mixed comment, mentions that information gaps may be a challenge to operationalisation
Issues associated with metrics	Mixed comments, mentions that overcoming issues associated with metrics may be a challenge to operationalisation
Negative comments	Responses conveying a negative sentiment towards the feasibility of real-world adaptation
Marine connectivity	Negative comment, rationale relating to marine connectivity
Monitoring and compliance issues	Negative comment, rationale relating to monitoring and compliance issues
Positive comments	Responses conveying a positive sentiment towards the feasibility of real-world adaptation
Possible - no clear reason given	Positive comment, no clear rationale articulated
Possible - similarity to Defra metric	Positive comment, rationale relating to its similarity to the Defra metric
B) Potential metric prescribers	Potential bodies that might prescribe a metric of this kind
Government	Comments suggesting that a government might prescribe the metric
Multilateral government bodies	Comments suggesting that a multilateral government body might prescribe the metric
Standards organisations	Comments suggesting that standards organisations might prescribe

Name	Description
	the metric
Sustainability certification programmes	Comments suggesting that a sustainability certification standard might prescribe the metric
C) Potential metric users	Potential fisheries that might use a metric of this kind
Any fishery	Comments suggesting that any fishery type might use the metric
Benthic impact fisheries	Comments suggesting that fisheries with a direct benthic impact might use the metric
Sustainability fishery leaders or aspiring ones	Comments suggesting that sustainability fishery leaders or aspiring sustainability leaders might use the metric
D) Suggested steps forward	Suggested steps forward to operationalise a metric of this kind
Account for recent regulations imposed on fishers	Comments suggesting that recent regulations imposed on fishers should be considered when operationalising the goal
Finding a way to demonstrate next level performance	Comments suggesting that finding ways for fisheries to demonstrate their next level environmental performance (if they take actions towards nature positive) will be important for operationalisation
Real world fishery uptake examples	Comments suggesting that providing real world examples of fishery leaders taking action towards the nature positive goal will be important for operationalisation
Simple and positive framing	Comments suggesting that providing a simple and positive framing of the nature positive goal will be important for operationalising it
Stakeholder engagement	Comments suggesting that stakeholder engagement will be important for operationalising the goal
3) Operationalising the NP fisheries goal	Potential drivers and challenges associated with operationalising the nature positive goal for fisheries, as suggested by fisheries experts
Drivers of operationalisation	Potential driving actions of operationalising the nature positive goal
Combination of both	Comments suggesting regulatory and voluntary actions will be required
Regulatory actions	Comments suggesting regulatory actions will be required
Voluntary actions	Comments suggesting voluntary actions will be required
Framing the goal for uptake	Suggested framings of the goal to increase uptake by industry
Step-by-step process	Comments suggesting the goal should be framed as a step-by-step process with milestones on the way
Link NP to existing terms	Comments suggesting the goal should be linked to existing terms
Simple and positive framing	Comments suggesting that the goal should be framed in a simple and positive way
4) Perception of the NP fisheries goal	Perception of the nature positive goal for fisheries
A) Mixed comments	Responses conveying a positive sentiment towards the goal in theory but also point to some reservations
Aspirational	Mixed comment, mentions that the goal may be too aspirational given the current state of fisheries
Dependent on impact on industry	Mixed comment, mentions that it will depend on what would be required of industry
Existence of related terms	Mixed comment, mentions that the existence of related terms may lead to resistance

Name	Description
Extractive nature of fisheries	Mixed comment, mentions that the extractive nature of fisheries makes it difficult to understand how the goal should be applied
B) Negative comments	Responses conveying a negative sentiment towards the goal
Added pressure on industry	Negative comment, rationale that it would add pressure on industry
C) Positive comments	Responses conveying a positive sentiment towards the goal
Aligns with ecosystem-based management commitments	Positive comment, rationale relating to link to ecosystem-based management commitments
Aligns with international agreements	Positive comment, rationale relating to link to international targets
Recognition of the importance of healthy ecosystems	Positive comment, rationale relating to the awareness of the importance of healthy ecosystems for fishing

Appendix VII: Fisheries management measures under the mitigation hierarchy

Operational fishery variables	Example effect on biodiversity	Examples of use in fishery management plans and policy	Key references
Avoidance: Avoid risk of negative impacts of direct fisheries operations on biodiversity.			
Spatial location of fishing activity	Spatial trends in catch rates related to habitat preferences and migration patterns of target stock and bycatch species Area-based management can prevent impacts of fisheries operations on vulnerable habitats and reduce chances of gear loss and ghostfishing by ALDFG	No-take MPAs (e.g., Lamlash, UK) Fisheries Restricted areas (e.g., in the Mediterranean Sea to protect essential fish habitats) Permanent closures to particular vessels (e.g., shark sanctuaries ban commercial shark fishing)	Booth et al. (2019), FAO (n.d.), Bromhead et al. (2012), Jacob et al. (2016), Ridge (2021), Schopka et al. (2010), Stewart et al. (2020).
Time of year or season of fishing activity	Seasonal time-area closures avoid fishing during critical periods of species' biological cycles such as spawning, seasonal migrations or aggregations and can provide ecosystems with time to recover	Direct regulation of fishing seasons (e.g., to protect spawning grounds of cod in Iceland) Time-area closures once catch limits have been met (e.g. shark FMPs for Gulf of Alaska)	
Depth of fishing activity	Depth trends in catch rates related to habitat preferences and movement patterns of target stock and bycatch species Impacts on habitat can vary depending on the depth of operations and so can the chance of gear loss and ghostfishing	Bans of bottom trawling (e.g., to protect seabed habitat in Inner Dowsing, UK)	

Operational fishery variables	Example effect on biodiversity	Examples of use in existing fishery management plans and policy	Key references
Minimisation: Minimise the risk of negative impacts of direct fisheries operations on biodiversity.			
Fishing effort	Increased effort (vessel number, gears, vessel days) leads to increased catch rates and habitat/ecosystem impacts.	Direct regulation of fishing effort through limited entry and permits (e.g., U.S. New England Groundfish fishery). Direct regulation of fishing outputs through quotas and trip limits (e.g., UK fishing quotas). Direct regulation through a hybrid system based on both effort and output (e.g., EU policy examples).	ACAP (2019), Gladics et al. (2017), ISSF (2019), MMO (2016), Moreno et al., (2023), Standal et al. (2020), Stewart et al. (2020), Squires et al. (2017), Government of Scotland (2024), Thunberg et al. (2007), Werner et al. (2015),
Gear type	Different total catch, juvenile ratios and bycatch ratios, and impact on habitat and greater ecosystem for different gears.	Direct regulation of permitted gear (e.g., driftnet bans in the U.S.), shifts towards more selective gear (e.g., trawling bans within three of UK's MPAs, using modified gillnets to reduce seabird bycatch, use of streamer lines to reduce bycatch of seabirds (ACAP recommendation).	
Gear deployment time	Effects of time of day on catch rates of different species.	Regulation for when gear is set (e.g., West Coast U.S. fisheries set gear at night to reduce albatross bycatch).	
Bait	Bait type and features can impact the likelihood of bycatch.	Regulation of bait colour to reduce its visibility to non-target species (e.g. West Coast U.S. fisheries dye bait blue to reduce albatross bycatch).	
Attractants/deterrents	Effects of e.g. chemical cues and light cues vary between species.	Use of decoys to attract non-target animals away from fishing activities.	
Mesh size and tension	Selectivity for species/length/age is influenced by mesh size and tension. Mesh size can impact the likelihood of gear loss and ghostfishing of certain species and sizes of catch.	Regulations for minimum mesh size exist in most fisheries to conserve the spawning stock (e.g., UK fishing regulations in the North Sea).	
Gear material	Gear material influences the duration and efficiency of ghostfishing by ALDFG. Alternative gear materials can prevent the transfer of toxins derived from ALDFG into marine food webs.	Requirement for less durable, or biodegradable materials for some gear components (e.g., exist in some Norwegian fisheries; jelly-FAD trials in the WCPO).	

FAD management	FAD settings can lead to increased bycatch FAD designs can influence rates of ghostfishing by ALDFG.	FAD design regulations (e.g., some RFMOs have put in a requirement for non-entangling FADs).	
Gear marking and recovery	Gear marking systems facilitate relocating lost gear and identifying ownership by making gear easier to retrieve and thereby reduce ghostfishing by ALDFG.	Requirements for gear marking (e.g., UK government requires labels).	

Operational fishery variables	Example effect on biodiversity	Examples of use in existing fishery management plans and policy	Key references
Remediate: Remediate the risk of negative impacts of direct fisheries operations on biodiversity.			
Stock replenishment/ rebuilding	Replenishment of fish stocks through stock enhancements can improve population viability at the stock level and rebuild depleted stocks back to sustainable levels.	Marine fisheries stock enhancement programmes which release hatchery-reared juveniles into the wild (e.g., Florida Fish and Wildlife Conservation Commission's Stock Enhancement program for species such as red drum, common snook, and bay scallops).	Booth et al. (2019), Guillen et al. (2018), Little et al. (2015), Ramírez-Amaro et al. (2019), Robins et al. (1999), Taylor et al. (2017).
Gear type	Bycatch survival rates for some species vary with gear type.	Direct regulation of authorised gears (e.g., gear restriction in the north-west Gulf of Mexico to reduce bycatch mortality).	
Excluder/ escape devices	Excluder devices can decrease capture of large sharks, rays and turtles, and escape panels can increase survival for some species as well.	Direct regulation of gear specifications (e.g., all trawl nets in Queensland's east coast fisheries require bycatch reduction devices) Requirement for sea turtle excluder chain mat (e.g., in the Northwest Atlantic scallop dredge fishery)	
Post-capture handling	Practices such as reducing time out of the water and careful handling of bycatch species can increase post-capture survival.	Direct regulation of handling procedures or equipment on board to promote safe handling (e.g. all trawl nets in WA require on-board in-water sorting systems)	
Discarding	Discarding target stock individuals generally results in mortality but frequently does not get recorded.	Discard bans and landing obligation requiring all catches of target stock to be landed (e.g., landing obligation of the EU). Requirement for real-time spatial management approaches to reduce discards (e.g. US fisheries).	

Operational fishery variables	Example effect on biodiversity	Examples of use in existing fishery management plans and policy	Key references
Compensate: Compensate for any residual negative impacts of fisheries operations on target stock.			
Payments-in-kind	Fishers could contribute their time and knowledge to e.g. monitoring and management in the area	-	Booth et al. (2019), ISSF (2016), NOAA (2023), Squires & Garcia (2018), Swan et al. (2016).
Target stock/bycatch/gear loss tax or fine	Finance off-site conservation efforts within the range of species affected by fisheries operations, habitat restoration within the affected ecosystem, or improved compliance in a nearby MPA.	Voluntary bycatch tax s (e.g., that of the International Seafood Sustainability Foundation's (ISSF) to finance sea turtle nesting habitat)	
Habitat improvement or restoration	Restoration of habitat that has been degraded by fishery operations to remediate some of the damage.	Habitat restoration programmes (e.g. NOAA Fisheries fund projects aiming to restore habitat through the coastal National Fish Habitat Partnership).	
Species conservation translocations	Conservation translocations (including reinforcements and reintroductions) could be conducted to facilitate marine ecosystem recovery.	-	

Appendix VIII: Fishery reports for the three case studies

Bluefin tuna fishery report for steps A-D

A) Define the system

i) Assess the fishery

The fishery targets eastern Atlantic bluefin tuna (*Thunnus thynnus,* Linnaeus, 1758) stock within the Spanish Exclusive Economic Zone (EEZ) in the Strait of Gibraltar (Borges & Revenga, 2022).

<u>Fishing gear</u>

The fishery uses various fishing gear types, including handline and fishing rods (including with live bait), trolling activities, and a fishing method referred to as "to the stone" (a la piedra). Additionally, the fishery uses the greenstick fishing method which is considered very selective relative to other tuna fishing methods (Borges & Revenga, 2022).

<u>Overview of impacts</u>

The fishery under assessment is small (0.2% of the total allowable catch (TAC) for bluefin tuna in Spain) and so is unlikely to be a leading driver of negative impacts on biodiversity in the area. The footprint of the fishery can be broadly divided into its impact on target stock (Atlantic bluefin tuna), non-target species used as bait (round sardinella (*Sardinella aurita,* Valenciennes, 1847), Atlantic mackerel (*Scomber scombrus,* Linnaeus, 1758), Atlantic horse mackerel (*Trachurus trachurus,* Linnaeus, 1758) and bogue (*Boops boops,* Linnaeus, 1758)), habitat (where the stone ballast method is used), and other indirect ecosystem impacts, such as on killer whales (Borges & Revenga, 2022).

Impacts on target stock

Historically, the eastern Atlantic and Mediterranean bluefin tuna stock has faced significant pressure from fishing operations (Fromentin et al., 2005). Although stock assessments have indicated that overfishing is currently considered unlikely to be occurring in the present, the stock could still be overfished (Borges & Revenga, 2022). According to the International Commission for the Conservation of Atlantic Tunas (ICCAT), the stock's biomass has been increasing since 2007 and there has been a decrease in fishing mortality of both younger and older fish (ICCAT, 2020). However, the extent of the increase in spawning biomass is uncertain as estimations vary depending on the assumptions used in the models, such as whether mixing between the eastern and western bluefin tuna stock is included. The most pessimistic models, which assume no mixing, estimate that the level of the eastern stock is below the levels estimated for the 1970s. Most of the models do agree that the spawning biomass does not fluctuate around a level consistent with B_{MSY} nor the proxy of $B_{0.1}$ (currently being used as a reference point) (Borges & Revenga, 2022). Finally, although there is information available of the biology of bluefin tuna through extensive research programmes, uncertainties remain regarding stock structure, mixing and growth. Further study is also required into the impacts of fisheries operations on factors such as age and size structure, sex ratio and genetics of the bluefin tuna stock (Borges & Revenga, 2022; ICCAT, 2020; Riccioni et al. 2010).

Impacts on non-target species

The fishery is reported to have negligible bycatch, if any. This has been confirmed by observers (Borges & Revenga, 2022). However, the fishery uses locally sourced non-target species as live bait. The species used for this are sardinella (50%), Atlantic mackerel (25%), bogue (13%) and Atlantic horse mackerel (12%). While quantitative data on the use of bait species exists, information on the species' stock status is lacking. This raises concerns about potential overexploitation - particularly for some of these species which do not have any management measures in place (Borges & Revenga, 2022). Atlantic mackerel is subject to a TAC and there is evidence from ICES that the stock remains above F_{MSY} (ICES, 2020). Quantitative information on the origin and quantities of round sardinella and bogue are used by the fishery, however, there is no information available on the stock status of these species (Fishbase, n.d. a). Bogue has some management measures, including minimum landing size, but round sardinella does not - despite making up >5% of the fishery's catch (Borges & Revenga, 2022).

Additionally, other non-target species may be impacted by ghostfishing from abandoned, lost or otherwise discarded fishing gear (ALDFG). Although specific assessments for this fishery are lacking, globally it has been estimated that 23% of handlines are lost globally and 22% of trolling lines (Richardson et al., 2019).

Habitat impacts

The only reported direct impacts of this fishery on habitat are benthic habitat impacts from stone ballasting. The stone ballast fishing method involves dropping 3kg sandstones onto the seafloor (after tuna has bitten the hook), which is mainly soft and muddy bottom habitat generally considered robust to disturbance. The sandstones are expected to dissolve; however, this has not been tested and the stone dropping is not subject to any specific management measures (Borges & Revenga, 2022).

Additionally, gear loss and ALDFG from the fishery could have a significant impact on the habitat but, as previously mentioned, the frequency and impact of gear loss in this fishery has not been assessed.

Greater ecosystem impacts

Based on a global analysis of ecological indicators, the Gulf of Cádiz has been described as a stressed ecosystem, heavily influenced by historical exploitation by fisheries (Torres et al., 2013). The fishery's removal of bluefin tuna, a top predator, may have cascading effects on lower trophic levels, but the extent of these effects has not been studied for this system (Baum et al., 2009). The removal of tuna may, for instance, have consequences such as releasing an unusually large abundance of preys at lower levels (e.g. copepods, fish, cephalopods, and crustaceans). This could have cascading effects on the food chain and species composition in the ecosystem (Torres et al., 2013).

Another concern is indirect impacts of the fisheries' operations on the Gulf of Cádiz and Strait of Gibraltar's subpopulation of killer whales, a species considered Critically Endangered by the IUCN's Red List and Vulnerable in the Spanish National Catalogue of Endangered Species (Esteban et al., 2016). The killer whales compete with the fishery for their main prey, bluefin tuna. In general, indirect interactions between marine mammals and fisheries are poorly understood and typically unmanaged (Trites et al. 1997; Nelms, Alfaro-Shigueto et al. 2021). Although relatively little is known about exploitative competition between marine mammals and fisheries (e.g. Kaschner and Pauly 2005; Machado et al. 2016), multiple studies have shown that reductions in the abundance of prey species by fisheries can contribute to the decline of marine mammal populations (see Nelms, Alfaro-Shigueto et al. 2021). For the killer whale population in the Strait, it has been reported that population recruitment stopped due to low prey availability after 2005 when the bluefin tuna stock reached its lowest level (Esteban et al., 2016). Evidence from other killer whale ecotypes supports that killer whale fecundity is highly correlated with the abundance of their main prey species (Ward et al., 2009).

Measures to mitigate impacts on killer whale calf survival rates have been implemented in the handline and rod fishery for two months a year during spring/summer. These includes a non-transferable quota in the area identified to be a seasonal feeding ground of killer whales (Borges & Revenga, 2022). However, there is no evidence available for whether this measure are sufficient to prevent negative impacts on killer whales during the rest of the fishing season.
Notably, for fisheries using drop-line gear, a new interaction between two killer whale pods (2 out of 5) and the fisheries. This interaction involves the killer whales depredating tuna from the fishery's baited hooks. This hunting method requires less energy investment from the killer whales than their normal approach of chasing tuna (Esteban et al., 2016; Ward et al., 2009). There is some evidence that this interaction with fisheries may improve killer whale pods' breeding capacities (Esteban et al., 2016).

Finally, other potential impacts on the ecosystem may include impacts on species residing in the benthic habitat affected by stone ballasting and impacts of mixing of the water column by the greenstick and fishing line and rod methods. However, these impacts have not been studied or quantified.

ii) Define biodiversity components of management concern

Based on the assessment of the fishery and its ecological footprint, there is one primary management concern and several secondary ones. The primary management concern is the bluefin tuna stock itself because its biomass remains below Maximum Sustainable Yield (MSY), remaining uncertainties in the stock models, and general lack of information regarding stock structure, mixing and productivity (ICCAT, 2020; Borges & Revenga, 2022). Additionally, unreported past and current illegal catches of tuna in nearby areas do not seem to be accounted for in management (Borges & Revenga, 2022).

The killer whale population, categorised as vulnerable to extinction by the IUCN, is another primary management concern. The species is indirectly impacted by the fishery's operations through exploitative competition for bluefin tuna, their main prey (Esteban et al. 2016). Other secondary management concerns include indirect impacts of the fishery on other trophic levels (Ward et al., 2009; Esteban et al., 2016), lack of information in relation to the potential existence of VMEs in the area the fishery operates in, impacts on other non-target species through ghostfishing, and impacts of stone ballast fishing on the benthic habitat structure and species residing in the seabed (for which data is lacking). However, although these biodiversity components are all of management concern for this fishery, due to a lack of information and difficulties in quantifying indirect effects, it is primarily the impacts on the target stock that are addressed throughout the rest of this report.

iii) Assess risks to biodiversity

Biological characteristics and risks

Bluefin tuna

- Bluefin tuna reach 50% sexual maturity at 104 cm straight fork length (age 3 or 4) (Correiro et al., 2005). They are long-lived, with a lifespan of about 40 years (Rooker et al., 2007).
- Uncertainties exist regarding the stock-recruitment ratio and stock biomass recovery (Borges & Revenga, 2022). In short, there is an overall uncertainty regarding stock structure, stock mixing and growth and thus a comprehensive range of information on stock structure and productivity is not available (ICCAT, 2020; Borges & Revenga, 2022).
- The IUCN Conservation status of the bluefin tuna is 'least concern' and so risk of extinction is considered as low.
- In summary, there is a lack of information to determine the main biological risks for bluefin tuna with certainty, but they may include the population's stock-recruitment ratio, fecundity and survival of young.

Habitat

- The benthic habitat in the Gulf of Cádiz is mainly composed of muddy bottoms and mixed sediments (Borges & Revenga, 2022).
- The robustness or the level of resilience (or sensitivity) of the benthic habitat to disturbance might be its main biological risk factor, although sandy habitat is generally considered robust to disturbances relative to other benthic habitat types (Borges & Revenga, 2022).

Technical risks of the fishery's operations

Bluefin tuna

- The primary risk of fisheries operations is overfishing which could be driven by uncertainties regarding the stock-recruitment ratio, population fecundity, and the suitability of the reference points in use for management (i.e. incomplete scientific knowledge for effective management of the stock).
- Actions resulting from these uncertainties, such as increased fishing effort or changes in gear and fishing location, could lead to overfishing.

Habitat

- The main technical threat is encounterability of fishery gear with the habitat, where the stone ballast method is used as it leads to sandstones being dropped onto the seabed. Until the impact of this is quantified, particularly how long it would take the sandstones to erode, this represents a technical risk for habitats.

- Another potential risk is abandoned, lost, or discarded fishing gear encountering the habitat, though quantification of its impact is needed.

Socioeconomic (context)

- There is a lack of data/information on the socioeconomic context of the specific fishery under assessment. However, it is known that bluefin tuna is a highly valued catch, particularly in the sashimi and sushi markets. It has been estimated that 90% of the cultivated tuna harvest across fisheries in the Eastern Atlantic and Mediterranean is exported to Japan (Phyne et al., 2013).
- More recently, the market for this species has also expanded beyond Japan and as a result there is a strong incentive for both legal and illegal fishing. Hence, the use and value of bluefin tuna, particularly considering its growing demand, is an important socioeconomic risk that should be considered (Phyne et al., 2013).
- Another important risk to the bluefin tuna population is that due to being highly migratory it spans multiple zones of coastal state jurisdiction and areas of high seas. This means that it is impossible for a single state to manage the stock in its entirety. Instead, ensuring the sustainability of the fishery will require integration into a governance regime with adequate jurisdictional powers and scientific advice (Phyne et al., 2013).

Constraints (context)

- Limited information was available regarding the budget for monitoring, enforcement and implementation, as well as societal limits on acceptable damage to species or costs to people.
- Monitoring, control and surveillance is in place for the bluefin tuna fishery, but the effectiveness of these measures remains unclear. At the ICCAT level, the emphasis is on vessel registration, catch monitoring and diplomatic pressure on states suspected of engaging in illegal practices. The fishery under assessment monitors its catches and effort through paper logbooks which are filled in at sea and before landing, and sales declaration forms. However, there are not any scales on board and weights are instead estimated based on the tuna individual length (10% tolerance margin is allowed between estimated weight and true weight) (Borges & Revenga, 2022).
- More generally, compliance with management measures has historically been a significant challenge in the bluefin tuna fishery (Phyne et al., 2013)

B) Set goals and targets

Goal: Biodiversity Net Gain

Target: A 10% increase in richness and relative abundance of species and the extent of natural ecosystems within the sphere of influence of the fishery's operations.

Metric: Ideally a suite of indicators will be used as the response of any one indicator to a particular stressor may not reflect the response of all affected biodiversity to that stressor. Metrics that could be used for this case study include:

- Bluefin tuna stock: for abundance use estimates of actual stock size (from fishery-independent data) or, less ideally, tuna fishing mortality rate which includes discards (from fishery-dependent data). If possible, size-based indicators and stock genetic diversity indicators should also be used for bluefin tuna.
- Habitat-level indicators: extent of habitat types, proportion degraded habitat, habitat functionality, abundance of biomass of habitat-forming taxa.
- General: Relative species richness and abundance, genetic diversity trophodynamic indicators and/or ecological modelling, functional diversity indicator, biological indicators (using indicator species, ideally of different trophic levels), hydrological and physical-chemical indicators.

Baseline: Ideally, to align with the GBF, 2020 should be used as a baseline year. However, for this illustrative case study, 2022 will be the baseline year as that is when the most recent MSC assessment was conducted

Timeframe: Halt further losses by 2030 and restore the ecological condition of the affected system by 2050.

C) Explore management measures under each step of the mitigation hierarchy

i) Avoid:

- Spatio-temporal closures / seasonal closure

ii) Minimise:

- Fishing effort/output restrictions
- Artificial bait
- Gear type
- Gear material
- Seasonal management areas for noise reduction

iii) Remediate:

- Gear tracking and retrieving
- Retiring gear when damaged

iv) Compensate

- Habitat enhancement/creation
- Payments in kind
- Tax that goes towards conservation actions
- Technical assistance to other vessels

D) Explore transformative actions

v) <u>Transformative actions</u>

- Investment in research and development: To address gaps in the knowledge of the biodiversity impact of the fishery, the status of the target stock, habitat, impacts of ghostfishing on the ecosystem, and compensation measures for impacts etc.
- Social signalling actions: This could include sharing biodiversity goals and strategies with others.
- Engage in collaborations with others: Collaborations to drive structural change, such as donating some time to building collaborations with other bluefin tuna fisheries and other stakeholders.
- Advocate for seasonal area closures of bluefin tuna spawning grounds: It is thought that the creation of permanent bluefin tuna spawning ground sanctuaries in the Mediterranean Sea would be beneficial for the conservation and rebuilding of the stock (ICCAT, 2020)
- Advocate for new marine policies: This could include policies that would create a new status quo for the required fisheries' actions for biodiversity, to level the playing ground for fisheries.
- Technical assistance to other vessels: The fishery could help other fisheries to switch to using the greenstick method to fish tuna as this method has been identified as alternative fishing gear to limit impact of tuna fishing on non-target species (ICCAT, 2020). For instance, for pelagic longlines, a large percentage of the catch is composed by species such as pelagic sharks (e.g. Dulvy et al. 2021; Gallagher et al. 2014).
- Measures to address IUU bluefin tuna fishing occurring in Spain and Malta. E.g. encourage international fisheries organisations, multilateral bodies, and States to expand existing efforts to address IUU fishing, including through improved transparency and joint enforcement efforts that support comprehensive fisheries surveillance and compliance (Borges & Revenga, 2022).

E) Feasibility assessment: summary

The dimensions considered for this assessment were economic, social, institutional and technological. Following previous studies (Williams et al., 2021; Booth et al., 2019; Gupta et al., 2020), the guiding questions for each dimension that were addressed for this assessment using available information were:

- Dimension: Economic
  - Are there economic costs and trade-offs expected?
  - Are there any known economic barriers?
- Dimension: Social
  - How is this measure likely to be perceived by fishers?
- Dimension: Institutional
  - What are the human resources required to support implementation of the adaptation option? Is governance support required for this measure, e.g. through new policy? Is the governance or institutional in place a potential barrier for the adaptation of the measure?
  - Does the option require administrative support?

- Dimension: Technological
    - Are the technology and other administrative resources required for the measure available or could feasibly be implemented? Is technological potential for the measure a constraint?

Avoidance measure: Spatio-temporal closures of tuna spawning grounds

- Economic costs and trade-offs: There is some evidence that there could be a limited economic benefit, at least in the long-term, if there was a broader commitment to rebuilding the stock (Armsworth et al., 2010). I did not find any studies specific to this fishery but a study of the economic efficiency of time-area closures to protect spawning grounds of the same species in the Gulf of Mexico (Armsworth et al., 2010) found that time-area closures are predicted to be economically costly if there is little scope for recovery of the bluefin tuna stock. However, their models predicted that such closures would offer limited economic benefits if there were a broader commitment to rebuild the bluefin tuna population. They predicted that rebuilding of the bluefin tuna population would increase overall economic revenues from the fisheries by 460%. This suggests it is in the long-term economic interest of the fishery to protect the tuna stock as it could act as an insurance policy against future stock collapse and so help safeguard the jobs of fishermen who depend on it. This benefits of tuna sanctuaries is also supported by information for bluefin tuna released by PEW (PEW, 2015). Economic barriers: Economic losses are expected in the short-term for fishers, and additional monitoring and enforcement would ideally be required as well which would also be costly. Compensation to fishers will be required to make up for those.
- Expected perception of fishers: Closures of spawning areas likely to result in reduced catches as fish aggregate in these areas so likely to result in resistance from fishers and some form of compensation will be required.
- Institutional resources required: Administrative support would be required in the form of a policy for designating the closed area. Support to determine specifically where the spawning grounds are may also be required. No evidence that governance will be a barrier for this.
- Technological resources required: Ideally would require an electronic monitoring (EM) system to be implemented for more effective monitoring but that would require more resources. Tuna RFMOs are currently discussing the potential to use EM systems as an alternative data collection tool and there are several EM programmes and initiatives that have been developed in Spain in recent years (Ruiz et al., 2021), so implementing such a programme for this fishery may be feasible.

Minimisation measure: Phase out stone ballasting

- Economic costs and trade-offs: Could require purchase of more alternative gear types, but not necessarily. The fishery is currently using handline and fishing rod methods and trolling methods in addition to the stone ballast method (Borges & Revenga, 2022). Therefore, the fishery may be able to avoid buying new gear while still maintaining the same catches by using the other fishing methods for which they already have the gear. Not known how catch efficiency of the different fishing methods compare.

- Expected perception of fishers: Potential for resistance by fishers to this measure as it would require change (and potentially costs) to move away from stone ballasting.
- Institutional resources required: Policy banning stone ballasting for all fisheries, rather than it being a voluntary measure from fisheries, would support implementation of this measure.
- Technological resources required: The fishery is already using other gear types which are selective and do not have any direct habitat impacts. Stakeholder engagements could be useful to increase awareness and spread information about potential environmental impacts of stone ballasting.

Remediate measure: Habitat improvement efforts on-site (removal of sandstones dropped)

- Economic costs and trade-offs: Removing the sandstones dropped by the fishery would either require time and other resources for the fishery to do it or costs to pay e.g. a conservation body to do it. Associated trade-off that these resources could not then be allocated to something else.
- Expected perception of fishers: This measure is novel and would require resources from the fishery so there is potential for fisher resistance. Hitherto, the dropping of sandstones has not been subject to any regulations.
- Institutional resources required: Some kind of policy or regulatory action likely to be required, as well as information as to the best methods available to remove sandstones.
- Technological resources required: Additional monitoring and enforcement required and potentially new technologies. Stakeholder engagements could be useful to increase awareness and spread information about potential environmental impacts of stone ballasting.

Compensation measure: Fine/tax for impacts

- Economic costs and trade-offs: This measure would be relatively costly and so a trade-off would be that the fishery could not spend those resources on something else. Do not have sufficient information about the socio-economic context of this fishery to assess economic barriers but given the economic value of tuna species (PEW, 2015) it seems likely that the fishery does have resources to make some kind of a contribution.
- Expected perception of fishers: This would be a novel fine/tax so fisher resistance to paying would be expected.
- Institutional resources required: Policy and administrative support likely to be needed to implement this measure, including to collect the fines. As for the conservation fund this fine would

go towards this requires there being conservation organisations or equivalent use the money for habitat/species restoration measures or similar.

- Technological resources required: Costly monitoring may be necessary to ensure that fisheries pay the fines. Stakeholder engagements could be useful to increase awareness and spread information about environmental impacts of fishing etc.

Transformative action 1: Investment in research and development

- Economic costs and trade-offs: This would require economic costs to the fishery through a monetary contribution and/or other contributions to research and development. However, this could support long-term sustainability of the fishery as there are many remaining knowledge gaps about stocks, impact on the ecosystem, and potential compensation measures for this fishery which need to be filled to inform the management strategy of the fishery and allow it to take compensation actions to reach no net loss or net gain for its impacted biodiversity.
- Expected perception of fishers: No specific issues identified, may result in some resistance from the fishery. However, research is already integral to this fishery, and other fisheries, so not a novel measure in that sense.
- Institutional resources required: This measure would require establishing collaborations with research institutes, if these are not in place already.
- Technological resources required: There are no additional technological resources expected to be required for this measure.

Transformative action 2: Measures against illegal, unreported and unregulated fishing

- Economic costs and trade-offs: This measure would require resources but may be feasible. A few different ways the fishery could take action against IUU, including supporting policies, reporting IUU etc., costs will depend on the specific measures chosen.
- Expected perception of fishers: No specific issues identified; measures of this kind are already in place in many places.
- Institutional resources required: Administrative support necessary as most action against IUU fishing happens at the regulatory level, including through laws and policies by government.
- Technological resources required: Not clear, depends on what specific actions the fishery takes. Online and/or in-person options could be possible for this measure.

Orange roughy fishery report for steps A-D

Orange roughy fishery

A) Define the system

i) Assess the fishery

Fishery Overview

New Zealand has the largest orange roughy (*Hoplostethus atlanticus,* Collett 1889*)* fisheries in the world, representing about 80% of the global catch. There are three MSC-certified orange roughy fisheries in New Zealand, representing 73% of New Zealand's orange roughy harvest. The fishery under assessment is one these three MSC-certified fisheries. It is confined to the ORH7A Challenger Plateau, including a small area on the west coast called Westpac Bank which is just outside the New Zealand EEZ boundary (Punt et al., 2022).

Fishing gear

The orange roughy fisheries in New Zealand use specified deepwater bottom trawl nets and fishing methods. Modern deepwater trawling is an aimed method of trawling, usually targeting relatively dense aggregations of fish, which are often located and targeted acoustically. The vessels in use by the fishery under assessment included 10 vessels in 2019, 2 of which were above 30m, 4 of which were between 30-40m and 4>40m (Punt et al., 2022).

Overview of impacts

The fishery makes up 100% of the TACC (1150t in 2020/21) in the ORH7A-WB area (Punt et al., 2022). The part of the fishery that operates in ORH 7A is estimated to have contacted 3% (2,551 km^2) of the seabed in that area, and 0.5% (65 km^2) of the Westpac Bank Area between 800-1600m depths from 2008-2017 (Punt et al., 2022). The impacts of the fishery can broadly be divided into impacts on target stock (orange roughy), other QMS species (spiky oreo (*Neocyttus rhomboidalis,* Gilchrist, 1906), ribaldo (*Mora moro,* Risso, 1810) and hake (*Merluccius australis,* Ginsburg, 1954), non-QMS species (rattail species, unidentified deepwater sharks and octopus species), ETP species (albatross and petrel species; various coral species), habitats (continental slope and UTFs, including VMEs) and greater ecosystem impacts (trophic impacts, structure and function). Based on catches by other orange roughy fisheries, many other species are frequently observed in low numbers in orange roughy catches, including invertebrate species; protected sharks and mammals have also occasionally been caught (Punt et al., 2022).

Target stock

The fishery targets the ORH7A stock on the Challenger Plateau. This stock is regarded as a single stock and managed separately from other regions around New Zealand. This distinction is supported by factors such as differences in size structure, parasite composition and allozyme frequency compared to stocks of other regions (Smith & McVeagh, 1997). Spawning also occurs on the Challenger Plateau at a similar time to fish in many nearby areas, providing further support for this distinction (FNZ, 2020).

The fishery for orange roughy in this area (ORH7A) began in the early 1980s. During the first years of the fishery, its catches were frequently above 10,000t. However, after the 1988-89 season, the orange roughy TACC was reduced by 75%. The TACC was then further reduced in the following seasons, and finally closed for commercial fishing during the 2000-2010 seasons. When the fishery was reponed for the 2010/11 fishing season, the TAC was 500t, but subsequently increased to 1600t for the 2014/15, and to 2058t in 2019/2020 (Punt et al. 2022).

The specific TACC for the ORH7A stock was set to 2058t in 2019/20 and 2t for Māori customary harvest (Minister of Fisheries, 2016). As a precautionary measure, the fishery has committed to enforcing the catch limit which is the lowest of the harvest control rules' outputs and approved by the Minister of Fisheries (DWG, 2021). According to the MSC assessment report of the fishery, it's harvest strategy is well-defined and responsive to the stock (Punt et al., 2022). The management target range, LRP and harvest control rule (0.045/year) were developed using an MSE framework parameterised for orange roughy in New Zealand (FNZ, 2020). This allowed the consideration of many of the uncertainties known to impact performance, including regarding natural mortality (Cordue 2014, 2019). However, although a broad range of uncertainties were considered, some were only partially or not at all accounted for, including stock structure and climate change (FNZ, 2020).

The stock assessment in 2019 used an age-structured population dynamics model parameterised with catch and monitoring data. This model was made within the CASAL package, to account for the biology of the species and the nature of the fishery (Bull et al., 2012). This assessment indicated that there is a high probability (0.99) that spawning biomass is above the precautionary reference point (PRU) of $0.2B_0$. It also indicated that there is very high probability (0.99) that the stock has been above the lower end of the management range ($0.3\text{-}0.5B_0$) since 2012. However, it should be noted that although similar assessment methods are widely used in fisheries globally, no formal evaluations of the assessment for orange roughy have been conducted (Punt et al., 2022) and it has not been reviewed by external scientists (FNZ, 2020; Punt et al., 2022).

In terms of monitoring, the harvest strategy relies on information from catch, surveys and age compositions (Punt et al., 2022). The Ministry for Primary Industries (MPI) monitors catch reports and fishing patterns to ensure compliance with regulations. The government's fisheries observer programme aims for 30% effort coverage for the stock. There are also acoustic surveys of the stock scheduled to run every 3 years (FNZ, 2020). Information from these surveys will feed into the stock assessments and support application of the harvest control rule (FNZ, 2020). Biomass and age-frequency estimates are also gathered from surveys and commercial catches. This data contributes to improving understanding of population dynamics and informing management decisions. Finally, Fisheries New Zealand (FNZ) also has a 5-year plan outlining a programme for research and monitoring of orange roughy (FNZ, 2020).

Non-target species

General for orange roughy fisheries: Estimates of annual non-target catch and discard levels of non-target species in New Zealand's orange roughy fisheries have been recorded since 1988 (e.g. Clark et al. 2000; Finucci et al. 2019). Orange roughy target fishing catches a relatively small amount of bycatch (MRAG Americas, 2016). Based on a 5-year average, 90.6% of the catch typically consists of either orange roughy or other primary species. However, a number of species have been observed in low numbers, with most being non-commercial species, including invertebrates such as squid. All catches of species managed under the Quota Management System are required by law to be accurately recorded, reported and landed, apart from a few prescribed exceptions for landings (Punt et al., 2022).

In the ORH7A fishery, the most abundant non-target species include spiky oreo *(Neocyttus rhomboidalis)* which makes up 1.85% of the fishery's catch, followed by ribaldo *(Mora moro)* at 1%, and hake at 0.5%. These species are not considered highly likely to be above their PRI, according to the fishery's MSC assessment report (Punt et al., 2022). Other, less abundant non-target species include the rattail species complex which makes up 0.7% of the catch, unidentified deepwater sharks (0.40%), long-nosed chimera at 0.28% of the catch, and unidentified species of octopus at 0.05% (Punt et al., 2022).

Monitoring of secondary species is done using catch, observer, and survey data. If sustainability or utilisation issues arise, these species may also get moved to the Quota Management System (QMS) or other management measures may be implemented. The information used to identify such issues includes landings, catches of the top three non-QMS species in e-logbooks, observers, and trawl surveys. However, there is no direct management strategy in place for the secondary species and uncertainties in monitoring exist, potentially impacting the effectiveness of these protection measures (Punt et al., 2022).

Sharks

The management of sharks in New Zealand is done according to the National Plan of Action for sharks, established in 2013. This plan includes expert-based assessments to analyse shark vulnerability and prioritise actions for species at higher risk from fishing. Fisheries managers have also started work with observers and the industry to increase reporting of shark catches to the level of species. The aim is to combine this information with risk assessment frameworks to provide better information for management decisions (MPI, 2013).

Management measures for specific species of sharks depends on the frequency of catch and other factors such as their vulnerability to fishing (categories: QMS, non-QMS, protected, and CITES-listed but otherwise not protected). Shark finning is banned and there are measures in place within the fishery to prevent it. These include a requirement that fins must be landed wet and either attached or reattached to the shark. Enforcement actions have not reported any shark finning violations in the fishery for the period 2016-21. As for regulations of discards, fishers are allowed to return some QMS sharks (dead or alive) back to the sea. Nonetheless, all landings, including discards, are counted against the Total Allowable Catch (TAC) for the species and against annual catch entitlements (MPI, 2013).

ETP species

Orange roughy trawl fisheries are overall considered low risk for captures of ETP (Endangered, Threatened and Protected) species such as seabirds, marine mammals and sharks. However, MSC-certified orange roughy fisheries (not the one under assessment) have reported captures of protected shark species (basking shark and smalltooth sandtiger sharks) and mammals (fur seals) (Punt et al., 2022).

As for seabirds, observed incidental captures are used to model the estimated annual captures based on total trawl tons undertaken. Salvin's albatross and Chatham Island albatross are the most frequently captured species. Petrels are the most frequently captured other bird taxon. In the ORH7A fishery, observed captures over the most recent 5-year period are only 3. The proportion of birds released alive has also increased in recent years for deepwater trawl fisheries. Further, as a precautionary measure, it is assumed in assessments and models that 50% of birds released alive will not survive (Richard et al., 2017).

Overall, the orange roughy fishery is not considered to cause significant detrimental direct effects on ETP species. However, as for indirect effects on ETP species by the fishery, things are less certain. Although no ETP species have been identified for which orange roughy is a significant element of their diet and competition between the fishery and ETP species for food is considered extremely unlikely (because levels of bycatch are low) (Dunn 2013), there is a possible effect from trawl 'sediment plume' on corals (MPI, 2013).

The management strategy for ETP species includes national requirements for protection and rebuilding (Punt et al., 2022). Various sources of information, including observer data, research surveys, VMS coverage (in relation to coral habitat and BPAs), and ecological risk assessments, support the quantification of fishery-related mortality and the impact of fishing on ETP species (Punt et al., 2022). Vessels are legally required to report all captures of ETP species to the Ministry (FNZ, 2019). Additionally, the MPI has a science observer programme for ETP species caught by the fishery sector and the Deepwater Group (DWG) employs an Environmental Liaison Officer to help with ensuring vessels comply with requirements (Punt et al., 2022). When impacts of fishing reach a level considered to cause adverse effects on the marine environment, measures are taken following the Conservation Act 1987 and the Department of Conservation implements set measures to address the impacts (Punt et al., 2022).

<u>Coral (ETP species)</u>

Deepwater hard corals are protected under the New Zealand Wildlife Act. However, it is not forbidden to catch these corals in areas outside of designated protection areas and no catch limits are prescribed. Coral caught by the ORH7A-WB fishery include bamboo coral, *Bathypathes* spp, black coral, bottlebrush coral, *Callogorgia* spp., *Dendrobathypathes* spp., golden coral, gorgonian coral, *leiopathes* spp., solitary bowl coral, and stony coral (Punt et al., 2022).

A key tool to assess the probable effects of trawl fishing on ETP coral communities for the deepwater fisheries has been to estimate the extent of overlap between the fishery and the observed coral distribution (Anderson et al., 2015). However, although there have been several recent improvements in modelling the distribution of coral taxa, the observed coral dataset is not representative of overall distribution. Moreover, the research data used from trawl surveys were not focused on assessing the extent of epibenthic fauna and so may not accurately reflect coral distribution in the entire area (Punt et al., 2022). As for information on coral recovery, a study in the area found very little evidence of stony coral recovery in the UTFs surveyed, including one that had been closed to trawling for 15 years (Clark et al., 2019). A recent survey in 2020 had more hopeful results as it found evidence of new clumps of stony coral polyps growing on coral rubble on a heavily fished UTF. This suggests that corals do have some scope for recovery from effects of trawling, albeit on a decadal scale. It has been suggested that coral diversity may be maintained in nearby areas not accessible to trawl gear and that this will provide a potential source for recovery if trawling were to stop (Consalvey et al., 2006).

To account for the susceptibility of corals to interactions with trawl gear, New Zealand has established seamount area closures and benthic protection areas to protect corals and other sessile benthic fauna. Currently over 31% of the seabed within the territorial Sea and EEZ are protected from bottom trawling and dredging (Helson et al., 2010). Monitoring of these measures is done by the ministry via 24/7 electronic monitoring of fishing vessel locality, and there are penalties in place for transgression in protected areas (Punt et al., 2022).

Other monitoring of corals which form part of the strategy for managing impacts on ETP species includes the previously mentioned information collected through observers, vessel monitoring systems, research surveys and other research projects. Additionally, analysis and monitoring of the ORH fishery trawl footprint in relation to ETP coral groups and the new benthic operational procedures will enable better quantification of captures of live coral by tows. This provides quantitative information to assess impacts and track threats to ETP corals. However, there is also possible effect from trawl ‘sediment plumes’ on corals but there have not been any studies specifically examining sediment mobilisation by fishing gear in deep-sea fisheries and its effects (MPI, 2013; Punt et al., 2022).

Habitats

Orange roughy fishing in New Zealand occurs over flat seabed on the continental slope and on Underwater Topographical Features (UTFs). The Chatham Rise region is dominated by sand, with very little mud and a few areas of gravel. The areas of gravel have large concentrations of glauconite and phosphate nodules (Glasby & Summerhayes 1975), which make up hard substrate for corals. Within the fishery under assessment there are no seamounts, but other UTFs are impacted by the fishery, along with continental slope areas. Continental slopes are flatter, often do not have any erect epifauna, and typically are characterised by muddy or sandy substrates. UTFs, on the other hand, are often aggregation sites for many species and provide important benthic habitats for fish species and many invertebrates (Punt et al., 2022).

The UTF habitat type at depths encountered by the fishery qualify as a Vulnerable Marine Ecosystem (VME) because of their functional significance, fragility, slow recovery and structural complexity. Within New Zealand’s EEZ there is good information available on the location and features of UTFs. Only approximately 34% of seabed accessible to fishing that is shallower than 1500m are open to fishing, and the rest is within BPAs and SCAs not open to fishing. Within ORH7A-WB, there are five known UTFs, of which four have been fished, and of the 535 known UTFs in the New Zealand EEZ, 144 (27%) have been fished in recent years. Out of the UTFs in ORH7A-WB that have been fished in the last 3 years, the contacted areas make up 38% (Punt et al., 2022).

Relevant data from observers, vessel monitoring, and research programmes provide robust information on trawl footprint and habitat impact. As previously mentioned, observer monitoring covers around 30% of trawl tows of the fishery and this provides a good estimation of the fishery’s impact on vulnerable habitats. There are also specific benthic interaction measures being implemented by quota owners to closely monitor and minimise catches of live corals, such as a trigger point (50kg) for catches of live coral BMA indicator taxa. As for VME habitats, there are requirements in place to prevent irreversible damage. However, the physical impacts of gear on habitat types have not been fully quantified, and habitat management strategies for non-MSC fisheries have not been evaluated. Additionally, the distribution of all habitats (including minor ones) is not known, and changes in all habitat distributions over time are not measured (Baird and Mules, in press; Punt et al., 2022).

Greater ecosystem impacts

Research on trophic interactions in orange roughy fishing grounds from the Chatham Rise indicates high ecological importance of benthic invertebrates, macro-zooplankton and mesopelagic fish (Pinkerton 2008; 2011). However, research does not provide evidence of loss of functional components or species in the ecosystem nor significant changes in the composition of orange roughy prey, predators or competitors (Dunn 2013). Additionally, monitoring of meso-pelagic biomass on the Chatham Rise suggests no significant changes between 2001 and 2010 (O'Driscoll et al. 2011). However, it should be noted that the wide area trawl and research surveys predominately sample depths shallower than the main orange roughy fishing grounds. Lastly, the low level of bycatch in the fishery also indicates direct ecosystem effects from removals are likely to be small (Punt et al., 2022).

The fishery's ecosystem-based elements of the management strategy focus on the different components of the ecosystem and considers fishery management, vulnerable species needs, and ETP species management. - i.e. biodiversity components covered in the sections above. According to the fishery's MSC assessment report, this represents a partial strategy to ensure the fishery does not pose a risk of serious or irreversible harm to ecosystem structure and function. However, it should be noted that these measures have hitherto only addressed individual ecosystem components, rather than broader ecosystem effects (Punt et al., 2022).

As for the information available for the management strategy, although the main functions of the components of the ecosystem have been identified and studied (e.g. Dunn 2013), there are limited assessments of fishery impacts on ecosystem elements that comprise structure and function. Information sources include stock assessments, QMS catch trends, observer data, and surveys that cover the target species, related species, as well as research. However, for some protected benthic species in particular, knowledge of ecosystem functions is minimal and the knowledge of the potential for trawl fisheries to affect the productivity of benthic communities is not well studied (Punt et al., 2022).

ii) Define biodiversity components of management concern

<u>Overview</u>

Based on the assessment of the fishery and its footprint, the primary management concerns are the orange roughy stock, impacts on bycatch and ETP species (primarily corals), habitat and greater ecosystem.

<u>Orange roughy</u>

- The orange roughy stock is of concern because of knowledge gaps that could be used to inform and improve the harvest strategy. These gaps include:

- That the relationship between spawning biomass and recruitment is not well known because of a lack of data on recruitment strength and the long lag between spawning and recruitment of the stock (Punt et al., 2022);
- Although MSE that the harvest strategy and harvest control rules are based on considers several sources of uncertainty (Cordue et al., 2014), it does not cover a very wide spectrum of uncertainties. Specifically, the uncertainty associated with the assessment was only approximately accounted for and at least one key uncertainty, stock structure, was not accounted for and the evaluation also did not consider the impact of climate change. There are currently no plans in place for surveys focused on improving biological and ecological knowledge of the orange roughy to address this gaps (Punt et al., 2022);
- There is no formal evaluation of the assessment method that is like the one for orange roughy and the assessment has not been formally reviewed by scientists external to the New Zealand assessment process (Punt et al., 2022);
- More generally, there is evidence that fishing may disrupt spawning and some spawning locations that were historically abundant no longer seem to occur. This is perhaps not surprising giving that the fishing catches peak during orange roughy spawning season - the fishery does not close during the spawning season. For instance, on the Chatham Rise, the main spawning aggregation no longer occurs in the Spawning Box but at Rekohu (FNZ, 2022). It should also be mentioned that orange roughy has historically been overfished, but the ORH7A-WB area was closed to commercial fishing for several years to allow recovery (Punt et al., 2022).

<u>Primary species (QMS species)</u>

- The main concern is that although they are monitored against a TACC, the TACC is not based on an analytical assessment for all species. This leaves a gap in information to use for evaluating with more certainty whether the strategy is achieving its objective (Punt et al., 2022).
- There is also not a biennial review of alternative measures that could be used to mitigate mortality of unwanted catch for all species (Punt et al., 2022).
- The impacts of catches are not known for all primary species (Punt et al., 2022).

<u>Minor secondary species (non-QMS species)</u>

- There is not enough evidence (limited stock assessments, uncertainty in monitoring) to conclude that rattail species are above biologically based limits (FNZ, 2020);
- There are measures in place for these species but no strategy for direct management of secondary species exists and it is not clear that all species that adequate measures are taken such moving species in need of further protection to QMS (Punt et al., 2022).

<u>ETP corals</u>

- Coral catches, given the slow recovery time of corals, lack of quantitative analysis of coral catches in trawls. There are new benthic operational procedures in place now though which will enable better quantification of live coral capture on a tow-by-tow basis (Punt et al., 2022);
- The potential negative indirect effects of trawling on corals from 'sediment plumes' (MPI, 2013);
- Lack of biennial review of alternative measures to use to mitigate mortality of ETP species more generally (Punt et al., 2022)

<u>Habitat</u>

- There needs to be a more detailed characterisation of the habitats, particularly evidence of recovery in previously fished areas (Punt et al., 2022).
- The physical impacts of the gear on habitat types have not been fully quantified (Punt et al., 2022).
- The distribution and changes in habitat distribution of commonly encountered and VME habitat types is known, but the distribution of all habitats (including minor ones) and changes in their distributions over time is not known (Punt et al., 2022).

<u>Greater ecosystem</u>

- There are limited studies on fishery impacts to actual ecosystem elements that comprise structure and function and management responses so far have addressed individual ecosystem components rather than broader ecosystem effects (Punt et al., 2022).
- Knowledge of ecosystem functions of benthic species in particular is minimal and the knowledge of the potential for trawl fisheries to affect the productivity of benthic communities is not well studied (Punt et al., 2022);
- The distribution of protected coral is sufficiently uncertain that it leads to uncertainties in developing a strategy for maintaining structure and function of coral and benthic components of the ecosystem (Punt et al., 2022).

iii) Assess risks to biodiversity

<u>Biological characteristics and risks</u>

Orange roughy

Distribution and habitat:

- The target stock species, orange roughy, has almost worldwide distribution but the majority of the world catch of this species has been taken from New Zealand (Branch, 2001).
- It is a deepwater fish species, that inhabits cold waters over steep continental slopes, ocean ridges and sea mounts (Branch, 2001).
- It has been found at depths from 700m to at least 1500m, but the maximum depths orange roughy inhabit are unknown (FNZ, 2020).

Size and longevity:

- In New Zealand waters, orange roughy reach a maximum size of about 50cm standard length and 3.6kg in weight, but the maximum size appears to vary amongst local populations. On average, the size is around 35cm (Horn et al., 1998).
- Long-lived species, with evidence suggesting lifespans of up to 120-130 years (FNZ, 2020). More recent methods have found evidence of older animals, 0.5% older than 200 years (Horn and Ó Maolagain, 2010).
- Slow growth rate and late age at maturity makes them vulnerable to overfishing and implies that populations can take a half century or longer before it can recover (Punt et al., 2022).

Maturity and spawning:

- Estimates of transition-zone maturity range from 23-31.5 years for fish from various New Zealand fishing grounds (Horn et al. 1998; Punt et al., 2022).
- Orange roughy are synchronous annual spawners that form spawning aggregations over sea hills (Mace, 1990).
- Smaller fish (up to 20cm) feed on crustaceans and larger fish (31cm and above) feed on teleosts and cephalopods (Stevens et al. 2011).
- Orange roughy predators are likely to change with fish size but may include deepwater dogfishes giant squid and sperm whales (Dunn et al. 2010; Punt et al., 2022).

Stock assessment and management:

- The ORH7-WC orange roughy stock has two target reference points, a soft limit and a hard limit. These are developed using a MSE framework parameterised for orange roughy of New Zealand (Cordue, 2014).
- The target reference points are 20% of the spawning stock biomass (0.2B0), above which recruitment should not be impaired. The management target range is 350% of the unfished spawning stock biomass. Assessment indicates the stock has been above the lower end of the management range since 2012 (Punt et al., 2022).

Extinction risk:

- Extinction risk has not been formally assessed by the IUCN Red List or CITES.

Spiky oreo (FishBase, n.d. b)

- Spiky oreo is found in all southern oceans at depths of between 200m and 1240m
- Size ranges up to 29cm.
- The fishery does not have biological reference points for spiky oreo, it is managed within an oreo complex.
- Its extinction risk has not been assessed by IUCN Red List or CITES.

Ribaldo (FishBase, n.d. c))

- Ribaldo is a deep-sea fish which is found worldwide in temperate seas, at depths of between 50 and 2500m.
- Size ranges up to 80cm.
- The fishery does not have a biological reference point for ribaldo.
- Its extinction risk was most recently listed by the IUCN as Least Concern in 2013.

Hake (FishBase, n.d. d)

- Hake is circumglobal in the southern hemisphere. It is divided into two distinct groups, a New Zealand population and a Patagonia population.
- Size ranges up to 155cm, but more common length is 80cm.
- The fishery does not have a biological reference point for hake, but the New Zealand hake trawl fishery is MSC-certified and that fishery has one for hake.
- Its extinction risk has not been assessed by the IUCN Red List or CITES.

Corals (includes black corals, gorgonians and hydrocorals)

- Corals caught by the ORH7A-WB fishery include (this is from observed and estimated catches for 2018/19-2019/20) bamboo coral, *Bathypathes* spp, black coral, bottlebrush coral, *Callogorgia* spp., *Dendrobathypathes* spp., golden coral, gorgonian coral, *leiopathes* spp., solitary bowl coral, and stony coral (Punt et al., 2022).
- The corals are not managed as separate species by the fishery, and they do not have biological reference points. Relatively recently, the fishery has set a trigger point at 50kg of live coral BMA indicator taxa from a single tow or cumulatively on a single tow line, which, if met, is meant to trigger surveys, assessments, and other measures (Punt et al., 2022).
- Black corals are listed by the CITES Appendix II, but the other species complexes are not, although species from some of the families are listed (by CITES or IUCN Red List) (Punt et al., 2022).
- In general, most coral polyps with a colony produce oocytes and so colony fecundity increases as colony size increases and vice versa (Punt et al., 2022).

Habitat

- The sensitivity or resilience of the benthic habitat to disturbance is generally not well known, but it is known that the recovery for some UTF habitats such as reef-building stony coral habitat, is slow (takes decades at least) (Punt et al., 2022).
- More detailed characterisation of the impacted habitat, including evidence of recovery in previously fished areas, is needed.

<u>Technical risks of the fishery's operations</u>

Orange roughy

- For the target stock, the primary risk of the fishery's operations is overfishing which could be driven by uncertainties behind and limitations of the stock assessment and information for the harvest strategy, as previously outlined. These uncertainties could lead to actions that could drive overfishing of the orange roughy stock, such as increased TACC, change in fishing location or gear types.

Spiky oreo, ribaldo, hake

- The main technical threat to the other QMS species is encounterability as their habitat preference overlaps with that of orange roughy and so are at a risk of encountering the trawls.
- Secondly, catchability is another potential technical risk, but this is not something that seems to have been assessed for these species.
- Finally, survivability is another technical risk as it is estimated that 50% or more of ribaldo are discarded (Punt et al., 2022). Spiky oreo and hake are generally landed so survivability is not as an important risk as it could be estimated that catches will lead to 100% mortality.

Habitat

- The main technical threats to the habitats are their encounterability with the bottom trawls and the extent of the impact (i.e. how frequently dredged and whether impact is carried out year after year) and penetration depth of gears

Corals

- The main technical threats to corals are expected to be similar to the ones for habitat, primarily relating to their risk of encountering bottom trawls and fishing intensity.
- There is also risk of indirect effects from sediment plumes and it is predicted that the effects of sedimentation will likely be greater on slope habitat where clumps of coral occur on rocky patches within otherwise sandy or muddy habitat.
- Trawling on UTFs will produce varying levels of sedimentation depending on the type of substratum, while elevated currents around topographic features will move the sediment along relatively rapidly (Punt et al., 2022).

<u>Socioeconomic (context)</u>

Orange roughy

- Orange roughy has been an important commercial species in New Zealand since fishing of the species began in the winter of 1979. Most orange roughy is exported, with little consumed domestically (MPI, 2023).
- The majority of orange roughy processed in New Zealand is exported as frozen fillets, with 80% by volume being exported to the USA (worth $NZ 35.7 million in 2022) and 14% to Australia (MPI, 2023). China is also an important market for frozen whole orange roughy, worth $NZ 12.6

million in 2022. Orange roughy quota across all fisheries (including ones certified by the MSC), was estimated in 2009 to be worth $282 million, and in 2014 orange roughy exports generated 36$ million for the New Zealand economy. Overall, though lacking information on just how important it is (including relative to other fisheries or industries), both socially and economically. It should also be noted that the fishery being assessed here is the one with the lowest TACC and lowest % of bycatch of the three MSC-certified orange roughy fisheries in New Zealand (MPI, 2023).

Constraints (context)

- There is a lack of information for the fishery concerning the budget for monitoring, enforcement, and implementation.

Current monitoring system (Punt et al., 2022):

- The current system for monitoring, surveillance and enforcement is considered comprehensive and effective. It involves:
- (1) compulsory use of satellite-based Vessel Monitoring System (VMS) with an onboard automatic location communicator (ALC);
- (2) government observers on board that may observe fishing, transhipment and transportation to collect any information on orange roughy fisheries resources (20-50% coverage). This includes information to monitor the effects of orange roughy fishing on the aquatic environment;
- (3) accurate recordkeeping and reporting requirements ensure auditable and traceable records to prevent catches from exceeding allocated quotas

Opportunities for improvement:

- The fishery would benefit from further measures to strengthen the credibility of the current monitoring system, including implementing an electronic monitoring system to monitor all catches, including bycatch and discards.
- However, there is a lack of information to determine whether there is enough budget for implementation and enforcement of such systems.

Societal limits:

- As for societal limits, the orange roughy fishery in New Zealand has been referred to as New Zealand's most controversial fishery. That is more the global narrative regarding the orange roughy fishery, evidence of more local views of the fishery are lacking.

B) Set goals and targets

Goal: Biodiversity Net Gain

Target: A 10% increase in richness and relative abundance of species and the extent of natural ecosystems within the sphere of influence of the fishery's operations.

Metric: In this case study a simplified metric will be used to assess the potential technical effectiveness of different management measures, but in real life ideally a suite of indicators should be used to capture the response of as many biodiversity components as possible... Metrics that could be used include:

- Estimates of stock size for target species (from fishery-independent data) or, less ideally, tuna fishing mortality rate which includes discards (from fishery-dependent data). If possible, size-based indicators and stock genetic diversity indicators as well.
- Bycatch: population growth, total mortality, number of animals...
- Habitat: change in the extent of different habitat types, proportion of degraded habitat, habitat functionality, abundance of habitat-forming taxa

Baseline: 2020 ideally – here will have to use 2022 though as that is when the most recent MSC re-assessment was conducted (orange roughy was first MSC-certified in 2016)

Timeframe: Halt further losses by 2030 and restore the ecological condition of the affected system by 2050.

C) Explore management measures under each step of the MH:

i) Avoid:

Spatio-temporal closures / seasonal closures / real time closures

Depth restrictions

- If possible, catch orange roughy in shallower waters to avoid direct damage to benthic habitats, including UTFs. Chances of ghostfishing and gear loss are also impacted by depth.

ii) Minimise:

- Fishing effort/output restrictions
- Gear requirements

Other potential methods (lacking information on potential effectiveness in the context of this fishery): Gear deployment depth and/or time of day, attractants/deterrents, mesh size and tension, gear material. (Gear marking, buyback of vessels & and gear and other measures for addressing gear loss and subsequent ALDFG)

iii) Remediate:

- Post-capture handling of bycatch species
- Excluder/escape devices for sharks

(Buyback of vessels and gear, gear recovery etc. for addressing gear loss and subsequent ALDFG)

iv) Compensate:

- Tax for habitat enhancement/creation measures
- Species conservation translocations (including reinforcements and reintroductions)
- Payments-in-kind
- Tax/fines
- Technical assistance to other vessels

D) Explore management measures under each step of the MH:

v) <u>Transformative actions</u>

Investment in research and development

- The fishery could invest in research and development of gear that could reduce the environmental impact of bottom trawling, including on coral reefs and other benthic communities and habitats, and gear that could minimise bycatch
- The fishery could invest in research into whether orange roughy can be caught using gear methods other than bottom trawling, such as methods that can be used in slightly shallower waters and do not encounter the benthic habitat
- The fishery could invest in research and development of methods for habitat restoration and regeneration in the deep-sea marine habitats it impacts, for instance for corals and UTFs
- Innovation: The fishery could test (or contribute to testing) innovative measures, such as novel gear or fishing methods that could limit the impact of their operations on biodiversity

System changing actions

- The fishery could engage in collaborations across seascapes to drive structural change. The collaborations could focus on e.g. advocating (or lobbying governments) for more ambitious government policies that create a new status quo for fisheries actions or other marine policies or agreements that benefit biodiversity. These could include policies outlining a requirement for the implementation of seasonal closures of spawning areas or extending BPAs or SCAs. This would provide more buffer zones for corals and other benthic organisms which could support more rapid recovery if fishing were eventually stop completely in nearby areas as well. Moreover, as many knowledge gaps about deep-sea habitats exist, particularly regarding their potential recovery times, a more of a precautionary approach focusing on avoidance of impacts is required.
- The fishery could engage in collaborations across seascapes to drive structural change
- The fishery could initiate or support existing integrated seascape initiatives

Social signalling actions

- The fishery could share its biodiversity goals and strategies with others, e.g. the other eight orange roughy fisheries in New Zealand or others elsewhere in the world to encourage them to follow suit. They could also share them with consumers and others in their value chain.

E) Feasibility assessment: Summary

The dimensions considered for this assessment were economic, social, institutional and technological. Following previous studies (Williams et al., 2021; Booth et al., 2019; Gupta et al., 2020), the guiding questions for each dimension that were addressed for this assessment using available information were:

- Dimension: Economic

    - Are there economic costs and trade-offs expected?
    - Are there any known economic barriers?
- Dimension: Social
    - How is this measure likely to be perceived by fishers?
- Dimension: Institutional
    - What are the human resources required to support implementation of the adaptation option? Is governance support required for this measure, e.g. through new policy? Is the governance or institutional in place a potential barrier for the adaptation of the measure?
    - Does the option require administrative support?
- Dimension: Technological
    - Are the technology and other administrative resources required for the measure available or could feasibly be implemented? Is technological potential for the measure a constraint?

<u>Avoidance: Benthic Protection Areas (BPAs)</u>

- Economic costs and trade-offs: Not all areas currently open to the fishery are fished by the fishery (Punt et al., 2022) which suggests that additional BPAs could be established without direct costs to fishers. No known trade-offs or economic barriers.
- Expected perception of fishers: As BPAs are already a well-established measure, there are no direct losses to fishers expected and overall minimal impact on them predicted, resistance from fishers is expected to be minimal if the BPA is implemented in areas currently not fished.
- Institutional resources required: Policy required to designate areas as BPAs so institutional support is required. Not expected to be a barrier as many BPAs already exist in the area and globally there is increasing pressure to the extend the coverage of protected areas in the oceans (e.g. CBD, 2022).
- Technological resources required: There is already a good monitoring and compliance system in place for this fishery, including 24/7 surveillance of protected areas (see details in part A of this assessment) so that system could be used to monitor compliance with this measure as well. Stakeholder engagements would be useful to increase awareness and spread information about why this type of measure is required.

<u>Minimisation: Orange roughy catch reduction</u>

- Economic costs and trade-offs: Reports from the New Zealand MPI are available which outline the potential TAC changes for the 2019/20 season of the ORH7A fishery (MPI, 2019). The first recommended option was to maintain the stock above the midpoint of the (then) current management target for the next 8 years. The second option was 29% TAC increase which, the report suggested, would be expected to result in a slight decline in stock status but maintain it within the management target range for the next years. The report estimates that this would represent an increase of 460 tons to the TACC of the previous season which would add up to an additional export value of NZ 3.5$ million per year. Options 3-4 proposed a 38% and 52% increase to the TACC respectively. Option 2 was chosen, so the TAC was increased by 29%. Therefore, in short, decreasing the TAC of this fishery back to what it was in the years below (decreased again by 29%), would result in an some annual economic losses when compared to the other options. However, when compared with previous years this TACC has not been this high since before the fishery re-opened so in that sense it would not have any direct economic losses (MPI, 2019). More recently, for the fishing season 2023/24 all options presented to the Minister based on stock assessments were reductions in TACC (Minister of Fisheries, 2023). However, in the year before the fishery had not used up the entire quota so economic losses would actually have been close to 0. This suggests that this measure would be economically viable.

- Expected perception of fishers: There have been a lot of fluctuations in the allowed TACC for this fishery historically so a decrease in catches is not expected to be met with very strong resistance. There may still be resistance as an increased TACC would benefit them in the short-term
- Institutional resources required: As previously mentioned, one of the quota options for the 2019/20 fishing season was to maintain catches at the same level as the previous year. The support required from government would be to choose this option instead of the increase in catches for this fishery. Given the limits of the biological and stock data available for this fishery, the precautionary approach would be well advised.
- Technological resources required: There is already a good monitoring and compliance system in place for this fishery, (see details in part A of this assessment) so this system could be used for this measure as well. Stakeholder engagements would be useful to increase awareness and spread information about why this type of measure is required.

Remediation: Best handling and release protocols for bycatch species

- Economic costs and trade-offs: Improving handling and release protocols of unwanted bycatch species would require time, knowledge and effort from fishers but is not expected to have any direct economic losses. Obvious trade-off is that their time is valuable and could be spent doing things directly profitable to them instead. Therefore, compensation is likely to be required.
- Expected perception of fishers: Some change would be required of fishers, but they may already be fulfilling this measure to some extent. Potential issues around compliance may arise, some form of compensation will be important.
- Institutional resources required: Institutional support is not necessarily required for this measure but could support implementation, e.g. through regulatory measures and providing compensation to fisheries.

- Technological resources required: There is already a good monitoring and compliance system in place for this fishery, (see details in part A of this assessment) so this system could be used for this measure as well. Stakeholder engagements would be useful to increase awareness and spread information about why this type of measure is required.

Compensation: Contribute to nearby marine conservation efforts

- Economic costs and trade-offs: This would require direct economic costs to the fishery. There is a lack of information as to whether the fishery under assessment can afford these costs, but it may do.
- Expected perception of fishers: This measure is novel and would require resources from the fishery so there is potential for resistance.
- Institutional resources required: Some kind of policy and administrative support likely to be required.
- Technological resources required: There is already a good monitoring and compliance system in place for this fishery, (see details in part A of this assessment) so this system could be used for this measure as well. Stakeholder engagements would be useful to increase awareness and spread information about why this type of measure is required.

Transformative action 1: Advocate for closures of spawning grounds

- Economic costs and trade-offs: This measure would require some time and resources but likely to be feasible as the measure is quite flexible in terms of what is required. It may also lead to economic benefits to the fishery in the long-term through supporting the sustainability of the fishery, but it is unclear how short-term losses and long-term gains compare.
- Expected perception of fishers: No specific issues identified although there may be some resistance at first as this is a novel measure and closures of spawning grounds may reduce catches of the fishery, but this is something that needs to be looked into further.
- Institutional resources required: Administrative support required to support this measure as the ultimate goal of the measure is policy passage by local administration for closures of spawning grounds.
- Technological resources required: Online and/or in-person options possible for this measure. Online option would require some technological resources. Stakeholder engagements would be useful to increase awareness and spread information about why this type of measure is required.

Transformative action 2: Investment in research and development

- Economic costs and trade-offs: This would require economic costs to the fishery through a monetary contribution and/or other contributions to research and development. However, could support long-term sustainability of the fishery as there are many remaining knowledge gaps about stocks and the ecosystem and potential compensation measures for this fishery which need to be filled to inform the management strategy of the fishery and allow it to reach no net loss or net gain for its impacted biodiversity.

- Expected perception of fishers: No specific issues identified, may result in some resistance from the fishery. However, research is already integral to this and other fisheries so not a novel measure in that sense.
- Institutional resources required: This measure would require establishing collaborations with research institutes (if these are not in place already).
- Technological resources required: There are no additional technological resources expected to be required for this measure.

King scallop fishery report for steps A-D

<u>King scallop fishery</u>

A) Define the system

i) Assess the fishery

The fishery targets the Shetland Inshore king scallop *(Pecten maximus*, Linnaeus, 1758*)* stock and queen scallop *(Aequipecten opercularis,* Linnaeus, 1758*)* to a lesser degree. It is confined to the Shetland 6 nautical mile inshore waters. The inshore shellfish fishery in Shetland is of great historical, cultural and above all, current economic and social importance (Cappell et al., 2018).

<u>Fishing gear:</u> Scallop dredge (mobile gear). The dredge consists of a triangular frame leading to a mouth opening 0.83m wide, a tooth bar with a distance of 65mm between teeth, length of teeth is approximately 8-10cm long, and a bag of steel rings (75mm internal diameter) and netting back (75mm stretched mesh) (Cappell et al., 2018).

<u>Overview of impacts:</u> All the inshore scallop catches in the Shetlands are derived from this fishery. Based on VMS data, NAFC found that the overall fisheries footprint across 2013-2016, is approximately 4.84% (or 5.69% when scaled to the whole fleet) of the Shetland 6 nautical mile zone. While not all scallop vessels have a VMS, VMS accounts for more than 80% of landings. The fishery's footprint can broadly be classified into impacts on the target stock (king scallop), queen scallop (retained species), bycatch species (primary ones are sea urchins (*Echinus esculenta,* Linnaeus, 1758), horse mussels (*Modiolus modiolus*, Linnaeus, 1758), and brown crab (*Cancer pagurus,* Linnaeus, 1758), habitats (the predominant ones are mixed sand, coarse sand, muddy sand and gravel) and indirect ecosystem impacts (Cappell et al., 2018).

<u>Impacts on target stock:</u> According to recent stock assessments (2016), landings and effort remain at a high and stable level, but there has been a decline in recruitment of the target stock. There were several very strong year classes in the middle of the 2000s; since then, recruitment has been more moderate. However, a clear relationship between spawning stock biomass and recruitment has not

been identified, and the scallop stock has recovered from much lower spawning stock and recruitment levels in the past (Dobby et al., 2017). Further, estimates of pre-recruits to the fishery obtained using Virtual Population Analysis (VPA) indicate that the abundance of this age class (age 2) has been stable since 2000. Additionally, logbook data and estimations from VPA imply that the SSB has been at or above the LRP for several years. Therefore, the stock is not thought to be below a point where recruitment would be impaired. Nonetheless, given this decline, the MSS advises against increasing fishing effort and instead suggests that measures should be taken to protect the spawning stock (Marine Scotland, 2015; Cappell et al., 2018).

It should be noted though that there are considerable uncertainties and limitations associated with current estimates of recruitment and the stock status (Leslie et al., 2010; Marine Scotland, 2015; Cappell et al., 2022). Firstly, direct biomass data for scallops is lacking as the development of direct estimate of stock biomass from the stock survey has not been fully developed. Therefore, no estimate of biomass (B_{MSY}) and fishing mortality (F_{MSY}) at MSY currently exist. This is addressed by using a multiple stock indicator approach to stock assessment, a recognised method for such situations. These indicators are based on estimates from VPA for recruitment and logbook data. However, it was suggested by the MSC assessors that VPA may not necessarily be appropriate for sedentary species such as scallop (Cappell et al., 2022). Secondly, there is a lack of knowledge of the inherent uncertainties in the data used in the assessments and the robustness of the assessment to the uncertainties. It does not seem that a Management Strategy Evaluation (MSE) has been conducted to test the harvest strategy's robustness nor that alternative assessment methods have been tested. For instance, it does not seem that a spatial modelling approach has been tested even though such a model would be more suitable to use for a sedentary species like scallop (Cappell et al., 2018). The current spatial components included in the harvest control rules (HCRs) are that management actions get triggered when there is a decline in LPUE in two or more areas of the fishery and the potential for spatial closures of the fishery in case of local depletion (Cappell et al., 2018). The reference points used are also not standardised for season, fishing area and vessel effects but that would allow for a more consistent comparison with standardised stock indicators (Cappell et al., 2018). Further, uncertainty around annual stock indicator values is not evaluated using standardised statistical methods or computer-intensive methods (Leslie et al., 2010; Marine Scotland, 2015; Cappell et al., 2018).

Finally, the stock biomass reference points in use are for the whole stock and no fixed values have been agreed on to use as reference points in different regions of the fishery. This is despite that, as noted in Dobby et al. (2017), the population structure of Scottish scallop stocks is not well understood and there is no clear definition of what constitutes the Shetland scallop stock. Further, it is reported that the assessment areas may not be the most appropriate units given current fishing practices and connectivity between scallop populations (Cappell et al., 2018). This is a potential problem as recent stock assessments have identified significant differences in stock dynamics between different areas of the fishery. Therefore, ideally the stock assessment should consider LPUE indicators for each region rather than for the whole fishery, particularly since some regions of the fishery might have low stock indicators. Finally, it is not clear that the assessment of stock status has undergone peer review (Marine Trust, 2022; Leslie et al., 2010; Cappell et al., 2022).

<u>Impacts on queen scallop:</u> Queen scallop is landed in very small proportions, catches of the species averaged 1.14% of total landings between 2005-2015. However, there is limited information on what impact the fishery has on the stock. The queen scallop fishery is very sporadic and there is a high degree of variability in catches as it is very much influenced by market conditions. The MSC concluded that the stock is highly likely to be within biologically based limits (Capell et al., 2018). They based this conclusion on factors such as that queen scallops have a slightly different habitat preferences to king scallops, dredges used for kings are not very efficient for queens, and the fact that (due to these factors listed) queen scallops are landed in very small proportions. It should be noted though that there is no target reference point for queen scallops in the Shetlands, there are no harvest control rules in place, and there is no detailed collection of biological data available for them (Cappell et al., 2018).

<u>Impacts on bycatch species:</u> The bycatch species can be divided into the most commonly caught bycatch species, ETP species, and other species not recorded. A study by Shelmerdine (2010) identified 63 animals as bycatch (Shelmerdine 2010). 15 of these species made up 98.35% of the total catch weight. After king scallop, three bycatch species dominate the catches: sea urchin (10.6% of catches by weight); horse mussel (6.9% of catches by weight) and brown crab (6.6% of catches by weight). A study by Jenkins et al. (2011) on the impacts of scallop dredging on benthic megafauna (not done specifically for this fishery) found that capture efficiency for megafauna is low, ranging from 2-25% and so the majority of megafauna which encounter scallop dredges remain on the seafloor (Cappell et al., 2018).

Management measures put in place for the SSMP scallop dredge fishery constitute a partial strategy for managing bycatch species which, according to the MSC assessment report, is expected to maintain the main bycatch species at levels highly likely to be within biologically based limits and to ensure the fishery does not hinder their recovery and rebuilding (Cappell et al., 2018). Data to support this strategy and detect any increase in risk to main bycatch species is collected through annual mapping of efforts, landings and LPUE of the scallop fishery. However, the strategy in place is not specifically designed for managing the impact on the bycatch component and there is no ongoing monitoring of most bycatch species. For instance, recovery times of species after interacting with scallop dredging will depend on the species composition, background disturbance and fishing intensity, but most of this information is generally not reported for this fishery (Cappell et al., 2018).

For instance, sea urchins constitute on average 10.6% of catches, but dredges also impact sea urchins that do not get caught but just encounter the dredges. According to Jenkins et al. (2011), 53% of total sea urchins encountered by dredging were found to be left in good condition but 46% injured or crushed. Despite this impact, there is no ongoing monitoring of the impact of the fishery on sea urchins (Jenkins et al. 2001). The MSC report concluded that it is considered highly likely that sea urchins are within biologically based limits, primarily based on the fact that sea urchins prefer rocky boulder substrata which the dredges cannot access. However, it is clear based on sea urchin catch rates that the dredges do operate in habitat where sea urchins occur. Other arguments included in the MSC report for why the sea urchin stock is thought to be in good conditions is that they have an early maturation and a 53% survival rate when encountering scallop dredges (Jenkins et al., 2001; Cappell et al., 2018).

A second example is the second most common bycatch species, horse mussel, which constitutes on average 6.9% of catches. Horse mussel is an important reef forming benthic organism which is assessed as Near Threatened in the European Red list of Habitats (EU28, EU28+; European Commission, 2015). The scallop fishery regulators have closed areas with known horse mussel beds to scallop dredging to protect the main parts of the horse mussel stock from fishing impacts. This is the main argument used by the MSC to conclude that it is highly likely that the horse mussel stock is within biologically based limits. However, it seems concerning that the species still constitutes such a large portion of the fishery's catches given the near threatened status of the species in Europe and importance as a foundation species (Cappell et al., 2018).

A third example is the third most common bycatch species of the fishery, brown crab, which was found to constitute 6.6% of catches by weight (Shelmerdine, 2010). The brown crab is considered a 'shelf' species that is distributed across quite large geographical areas and multiple habitats. Brown crab is targeted by fisheries in Shetlands waters and so does have set limit and target reference points, harvest strategy and HCRs in that fishery.

<u>Impacts on ETP species</u>

The ETP species deemed most likely to be captured incidentally by scallop dredgers are primarily demersal elasmobranch species, such as common skate, angel shark and porbeagle – based on their temporal range, spatial range and evidence of interaction with the fishing gear (Cappell et al., 2018). However, the only elasmobranch species reported to have been caught in the scallop surveys and commercial trips of the Shetland scallop fishery are cuckoo ray, thornback ray and common skate. Out of these, only common skate is an ETP species, the others fall under the many bycatch species caught in relatively small quantities by the fishery. Four juvenile individuals of common skate and some empty egg cases were caught by the fishery in 2010. These skates were caught in 57 experimental dredge tows which adds up to a large impact when scaled up to the whole of the Shetland scallop fishery (Shelmerdine et al., 2010). Common skate have low recruitment (each female only produces between 25-50 eggs per year, some females only produce young every two years) and so any catches would be expected to have a significant negative impact on the population. However, the skates caught in 2010 are reported to have been alive and unharmed when caught and subsequently got released. Further, since then there have not been any reports of interactions with common skate, neither from fishermen nor independent surveys. This suggests that the capture of common skates was a one-off incidence. Overall, risk of an interaction between the fishery and common skate is considered low although the potential remains that such interactions may have occurred without being reported (Cappell et al., 2018).

Impacts on habitat

In general, scallop dredging can have significant impact on habitats and biota. For instance, it can result in the simplification of habitats and the removal of species (e.g. Auster et al., 1996; Bradshaw et al. 2000; Albrecht, 2013; Currie & Parry, 1996). The recovery times of habitats after scallop dredging varies from a few days in high tidal and wave swept areas to months in less exposed areas, and more than 3 years across sensitive biogenic reef habitats (Lambert et al., 2014). The level of impact also varies depending on the habitats impacted and how extensively these areas have been impacted by fisheries previously. Thus, to understand how habitats are impacted by dredging, knowledge of the habitat types, background disturbance, and fishing intensity is required (Cappell et al., 2018).

The seabed habitat of Shetland's inshore waters is mainly mixed sand, coarse sand, sandy kelp, muddy sand, and gravel. The fishery does not take place in areas of kelp though since these habitats are not known as suitable scallop habitats and fishermen want to avoid their gear getting entangled in kelp. The area is exposed to medium-strong tidal currents and most of the habitats are considered to be of medium sensitivity to scallop dredging. The scientific literature (see MSC report) shows that sand habitats are generally resilient to impacts of bottom gears. For other habitats (i.e. rock and gravel) for which recovery time could be longer, the potential overlap of the fishery is limited compared to the overall extent of these habitats (Cappell et al. 2018).

The Shetland inshore fishery has several restrictions regarding the type of dredge gear allowed. The degree of dredge effect used in the fishery is considered relatively small, as fewer dredges and lighter gear is used compared with typical fishing vessels used for scallop dredging near the mainland of Scotland. Further, the SSMO has implemented spatial management regulations and 15 closed zones to protect areas supporting sensitive seabeds such as seagrass, maerl and horse mussel beds. These closed areas and the marine spatial plan in use are based on a mapping effort of seabed types, biotopes, and sensitive habitats in the waters around the Shetland Islands (NAFC Marine Centre, 2015).

However, the physical impact of the gear on the habitat types within Shetland waters have not been fully quantified and the general habitat information used is mostly based on predictive mapping. Further information is needed to assess the impact of the fishery, including more robust information concerning the overlay of the fishery with different habitat types and evidence of the resilience of the specific habitats in this setting. Although there are closures in place to protect the habitat types considered most sensitive based on their recovery time, these mitigation measures do not protect or benefit most of the habitats within the area the fishery operates in. Furthermore, according to the MSC's report, full evidence showing that all sensitive biogenic habitats are protected effectively in their range is lacking.

Furthermore, the extent and importance of other seabed habitats in the waters around the Islands has led the Scottish Governments to designate two nature conservation Marine Protected Areas (MPAs) and three Special Areas of Conservation (SACs). One of the MPAs (Mousa to Boddam) was designated to conserve sand eels, and the other (Fetlar to Haroldswick) to conserve a range of seabed species and black guillemot. The MPAs cover habitats such as kelp and seaweed communities, shallow tide-swept coarse sands with burrowing bivalves, and circalittoral sand and coarse sediment habitats which are considered to be of medium sensitivity to impact by scallop dredging. Regardless, the majority of these habitats, even inside of the MPAs, are not protected by the SSMO's closed areas. In fact, significant fishing activity does take place within the MPAs (at least the one around Fetlar). Although protection required within MPAs does not find basis in the MSC Standard's requirements, it has been recommended by organisations such as Open Seas. Some studies (e.g. Dobby et al., 2017) have even recommended capping scallop dredge effort throughout Scotland's inshore. In short, only a very small percentage of Shetland's seas are protected from fishing and habitat types known to be at least of medium vulnerability to dredging are not protected. Thus, further studies are required to conclude whether the Spatial Management Plan in place protects a large enough area around the Shetland Islands to mitigate the environmental damage caused by scallop dredging.

Greater ecosystem impacts: In general, it is known that scallop dredging can have a significant impact on habitats and biota and a wider impact on the marine ecosystem, including through simplification of bottom fauna. Particularly in areas where scallop dredging is carried out year after year, the benthic community structure could be left in an altered state (as long as the fishery continues), and may end up consisting primarily of fauna more adapted to physical disturbances. As previously mentioned though, the recovery time of habitat and species will depend on factors such as fishing intensity, background disturbance and species composition (Bradshaw et al., 2000; Albrecht, 2013; Auster et al., 1996; Cappell et al., 2018).

The ecosystem structure of the North Sea ecosystem has been explored to some extent within Shetland's waters and the predator-prey relationships for the target, retained and most common bycatch species, are well understood (Mackinson & Daskalov, 2007). Additionally, research on the species directly impacted by the fishery provides some information on the consequences for the ecosystem. Scallops are not considered to be a keystone species, however, they do provide an important food source to starfish and brown crab, and many organisms prey on scallop spat. Based on this, and other available information, the MSC concluded that it is highly unlikely that a trophic cascade, significantly altered size composition, and severe changes in diversity will result from the current practices of the scallop fishery (Cappell et al., 2018).

However, it should be noted that issues remain including ecological impact escape and discard mortality, incidental megafauna interactions and habitat interactions (Cappell et al., 2018). Additionally, there are other ecosystem impacts reported for dredging more generally which do not seem have been studied for this fishery, including dredging bringing stones to the surface, sediment compaction and chemical changes, and increased vulnerability to predation for some species. In conclusion, although some information is available about the main consequences for the ecosystem through research (impacts of the fishery on the main species impacted and habitat), information is not available for the impacts of dredging on all different elements of the ecosystem (Cappell et al., 2018).

ii) Define biodiversity components of management concern

Based on the assessment of the fishery and its footprint, the primary management concerns for this fishery are the king scallop stock, habitat impacts, bycatch species including queen scallop, horse mussels, sea urchins, and potential catches of ETP species such as common skate. Brown crabs are not of a particular management concern for this fishery as they are managed by a different fishery specifically targeting brown crab in Shetland's waters.

King scallop is of management concern due to the recently recorded decline in recruitment, lack of direct biomass data, lack of a geographical modelling component in the stock assessment and HCRs, the fact that the reference points in use are unstandardised, a lack of evaluations for uncertainties around the annual stock indicator values, lack of peer review for stock assessment, and the fact that no fixed values have been agreed for reference points in different regions of the the fishery despite the knowledge that there are significant difference in stock dynamics between different areas (Cappell et al., 2018).

The different habitat types affected are another primary management concern, both in terms of the short- and long-term impacts as it is well-known that scallop dredging can have significant habitat impacts. Although there are restrictions in place to protect known areas of particularly sensitive habitats, there is a lack of research and the physical impact of the gear within the Shetland waters have not been fully quantified, the general habitat information used is mostly based on predictive mapping, the mitigation measures in place do not protect or benefit most of the habitats within the area that the fishery operates in. Further, MPAs and SACs around the Islands are not fully protected from fishing (Cappell et al., 2018).

Bycatch species are another primary management concern as 68 different bycatch species were identified for the fishery (Shelmerdine 2010), most of which are not described in the fishery's MSC report and have no ongoing monitoring. Out of the ones described, there is a general lack of data to base management on. For instance, the queen scallop stock lacks a target reference point and HCRs, and their stock status cannot be analytically assessed due to a lack of biological data. Similarly, for the other main bycatch species, including sea urchins and horse mussels, the main concern is that there is only a partial strategy in place for managing bycatch species and there is no ongoing monitoring of most bycatch species. Additionally, it is not possible to exclude the possibility that catches of ETP species such as common skate are going unreported and this constitutes another management concern. However, as there have not been any reported catches of common skate except in 2010 and since the baseline for this case study is 2016 as that is the most recent information of catches etc. used in the MSC 2018 report, common skate will not be included in most of this assessment (Shelmerdine et al., 2010; Cappell et al., 2018).

Potential impacts on the greater ecosystem are also of management concern. This includes issues including ecological impact escape and discard mortality, impacts such as dredging bringing stones to the surface, sediment compaction and chemical changes, and increased vulnerability to predation. However, as there is a lack of information for these greater ecosystem impacts, and given the general difficulty to quantify them, these impacts will not be directly considered in the rest of this report.

iii) Assess risks to biodiversity

Biological characteristics and risks

King scallop

Distribution and habitat (MarLin n.d. (a))

- The target stock species, king scallop, occurs along the European Atlantic coast from northern Norway, south to the Iberian Peninsula, most commonly in waters 20-70m deep.
- The scallops in Shetland have a coastal distribution within the 6nm inshore waters of the Shetland Islands and that is where the catches of the fishery under assessment are confined.

Based on this, it is assumed that the area covered by the fishery can reasonably be considered a stock which is not connected to other scallop stocks in Scotland.

- King scallops are found on clean firm sand and fine gravel and in currents which provide good feeding conditions. They are filter feeders and larval survival is promoted by good concentration and quality of food in the water column.

Lifestyle and reproduction (Cappell et al., 2018; MarLin n.d. (a))

- Their lifespan in Scottish waters is 20 years or more (MSS, 2014), but oldest individuals typically reach 10-11 years of age in exploited populations.
- They reach first maturity at 2 years and full maturity at 3-5 years. Their lifecycle can be divided into a free-swimming larval phase, and a largely sedentary juvenile and adult phase.
- Their size in heavily fished areas is heavily reduced, and those caught commercially rarely exceed 16cm (Minchin, 2003).
- King scallop fecundity is over 1,000,000 in terms of number of eggs, they are hermaphroditic, their reproductive frequency is annual protracted and their spawning season is around April to Sept/Oct. In exploited populations, the most abundant year classes are generally 4-6 years old.
- Recruitment is usually unpredictable as it depends not only on successful spawning and larval production but also on retention of larvae and transport of larvae into the area.
- Settlement in a particular area may also be unpredictable, leading to an unstable age structure. As a result of this, scallop beds frequently show a regional separation of year classes and spatial variability in age structure.

Management (Cappell et al., 2018; Dobby et al., 2016)

- The Shetland king scallop stock has two biological reference points in use, an LRP and a TRP. There are currently no direct estimates of biomass of scallops in Shetland, and hence multiple stock indicator approach to stock assessments is used. For setting the LRP the approach is to examine time series of stock indicators and then the LRP at the lowest observed value.
- The main stock indicator used is landing per unit effort (LPUE) which is considered as an index of stock abundance. For setting the TRP the data were examined for period of high LPUE which would be consistent with relatively higher abundance, and these were taken to represent a biomass consistent with MSY. They then take a precautionary approach as the TRP is set at 80% of the mean LPUE from these periods of high stable values

Extinction risk

- As for the extinction risk of king scallop, they do not appear on IUCN's Red List nor CITES appendices and based on the wider literature it does not seem that the species is threatened at the global level.

Sea urchins (Cappell et al., 2018; MarLin, n.d. (b))

- The edible sea urchin *(Echinus esculentus)* is common in all areas with hard substrates in the North Sea.
- It has a relatively high fecundity and early maturation. The sexes are separate and a single female sea urchin can produce up to twenty million eggs in one year, which then turn into larvae which after a few months develop into small sea urchins
- They grow up to 15-16cm in diameter at 7-8 years of age.
- There are no reference points available for the sea urchins around the Shetland waters.
- Their extinction risk has not been formally assessed by the IUCN, CITES or similar bodies but based on the wider literature it does not seem that the species is threatened at the global level. However, sea urchins can be very sensitive to any changes in their environment, such as water's pH and rising temperatures

Horse mussels (Cappell et al., 2018; MarLin, n.d. (c))

- Horse mussels (*Modiolus modiolus)* are bivalve molluscs ranges from Scandinavica and Iceland south to the Bay of Biscay. In the UK, it occurs all around the British Isles but is most common in the north.
- Their lifespan ranges from 20-100 years, with variable spawning seasons depending on location, fecundity (number of eggs) >1,000,000 and age at maturity is 3-8 years. Recruitment of horse mussel is highly variable seasonally, annually or with location (Holt et al. 1998).
- There are no biological reference points in use by the fishery for horse mussels.
- Although horse mussels are not listed by the IUCN or CITES, their beds are an OSPAR threatened and/or declining habitat (OSPAR, 2009), are recognised as biogenic reefs under the EU Habitats directive and as Near Threatened by the EU 28 and EU 28+ Red List of Threatened Species (Saunders, G., & Gubbay, S., 2016).
- Finally, horse mussel beds are sensitive to physical disturbance, surface and sub-surface abrasion, siltation changes and removal of on-target and target species

Habitats (Cappell et al., 2018)

- The habitat of Shetland's inshore waters affected by dredging is predominantly mixed sand, coarse sand, muddy sand, and gravel.
- The area is exposed to medium-strong tidal currents. The robustness or the level of resilience of the benthic habitat to disturbances might be its main biological risk factor.
- The recovery times of habitats after scallop dredging specifically varies from a few days in high tidal areas to months in less exposed sand and muddy sand areas.

- The habitat types within Shetland's inshore waters are considered to be of medium sensitivity to impacts by scallop dredging.

Technical risks of the fishery's operations

King scallop

- For the target stock the primary risk of fisheries operations is overfishing which could be driven by uncertainties around biomass estimates, the stock's recruitment level, and the stock assessment more generally as previously discussed. These uncertainties can lead to actions that could drive overfishing of the scallops, such as increased fishing effort, change in fishing location or gear types

Sea urchins

- The first main technical threats to sea urchins are encounterability. Although sea urchins prefer rocky boulder substrata which the dredges cannot access, they were found to constitute 10.6% of catches by weight and so are at a high risk of encountering dredges (Shelmerdine, 2010).
- Secondly, catchability is another technical risk to sea urchins. A study by Jenkins et al. (2011) found that capture efficiency for megafauna, including sea urchins, ranged from 2-25%. This suggests that the majority of megafauna which encounter scallop dredges remain on the seafloor, yet based on the catches of sea urchins by the fishery this risk is clearly still considerable.
- Thirdly, survivability is another technical risk to sea urchins. Jenkins et al. (2011) found that 53% of total sea urchins encountered by dredging were found to be left in good condition but 46% injured or dead. Although this suggests that the majority of sea urchins are unharmed by dredges, a considerable proportion is affected and some do die.

Horse mussels

- Similarly to sea urchins, the main technical risks to horse mussels are encounterability, catchability and survivability of horse mussels affected by the fishery.
- Although areas that are known to support horse mussel beds have been closed to the fishery and are monitored (at least on larger vessels with VMS), they were still found to constitute 6.9% of catches by weight (Shelmerdine, 2010). As for catchability, the study by Jenkins et al. (2011) for capture efficiency for megafauna included bivalves as well for the 2-25% capture efficiency value.
- Finally, the 6.9% that are caught do not survive, but it is not clear what the survivability is of individuals left on the seabed.

Habitats

- The main technical threats to the different habitat types are their encounterability with the scallop dredges and the extent of the impact (i.e. how frequently dredged and whether impact is carried out year after year) → **encounterability, extent of impact**

Constraints (context)

- There is a lack of information for the fishery concerning the budget for monitoring, enforcement, and implementation.
- There is currently routine monitoring in place and vessels above 10m are required to submit a monthly daily log sheet providing information on landings, discards and fishing effort which are used as a feedback mechanism for the monitoring strategy in place. Inshore VMS is also being trialled to enable closer spatial management of inshore vessels in relation to closed areas, but currently this is not a requirement for all vessels (only ones above a given size limit) (Punt et al., 2018).
- Nonetheless, the fishery would benefit from further measures to strengthen the credibility of the current monitoring system, including setting a requirement for VMS to be onboard all vessels and implementing an electronic monitoring system to monitor catches, bycatch and discards. However, there is a lack of information to determine whether there is enough budget for implementation and enforcement of such systems.
- As for societal limits on acceptable damage done by scallop dredging, although scallop fishing is considered to be of economic and cultural value, the Shetland scallop fishery have also been on the receiving end of protests and environmental campaigns against them by the public and conservation groups (Punt et al., 2018).

B) Set goals and targets

Goal: Biodiversity Net Gain

Target: A 10% increase in richness and relative abundance of species and the extent of natural ecosystems within the sphere of influence of the fishery's operations.

Metric: In this case study a simplified metric will be used to assess the potential technical effectiveness of different management measures, but in real life ideally a suite of indicators should be used to capture the response of as many biodiversity components as possible. Metrics that could be used include:

- Scallop stock: for abundance use estimates of actual stock size (from fishery-independent data) or, less ideally, tuna fishing mortality rate which includes discards (from fishery-dependent data). If possible, size-based indicators and stock genetic diversity indicators should also be used
- Bycatch species: population growth, total mortality, number of animals...
- Habitat-level indicators: change in the extent of the different habitat types, proportion of degraded habitat, habitat functionality, abundance of habitat-forming taxa

Baseline: 2020 ideally – here will have to use 2018 though as that is when the most recent MSC assessment was conducted.

Timeframe: Halt further losses by 2030 and restore the ecological condition of the affected system by 2050.

C) Explore management measures under each step of the MH:

i) Avoid:

- **Spatio-temporal closures** / seasonal closures / real time closures

ii) Minimise:

- Fishing effort/output restrictions
- Gear requirements
- Introduce boulder exclusion devices to prevent the loss of habitat features
- (Gear marking, buyback of vessels & gear and other measures for addressing gear loss and subsequent ALDFG)

iii) Remediate:

- Stock replenishments/rebuilding for some of the species
- Post-capture handling of bycatch species such as reducing time out of the water, gentle handling etc. can improve survival rates of bycatch species such as rays and skates
- (Gear recovery etc. for addressing gear loss and subsequent ALDFG)

iv) Compensate:

- Tax for habitat enhancement/creation measure
- Species conservation translocations (including reinforcements and reintroductions)
- Payments-in-kind
- Tax/fine for bycatch/target stock catches which goes towards local conservation actions

D) Explore transformative actions

v) Transformative actions

- Investment in research and development:
- Innovation: The fishery could fund tests of innovative measures in the field, or even conduct them – e.g. testing of novel gear or fishing methods that limit the impact of their operations on biodiversity. This could be into the robotic design mentioned under research for example
- Social signalling action: The fishery should share its biodiversity goals and strategies with others, e.g. other scallop dredges in Scotland or the UK, consumers, others in their value chain. The fishery could also engage in collaborations with other Scottish scallop fisheries to drive structural change
- System changing actions: The fishery could advocate for more ambitious government policies that create a new status quo for fisheries actions for biodiversity, petition or lobby governments to facilitate actions, e.g. to support specific marine policies or agreements. These policies could

be the protection of MPAs and SACs from fishing, closures of more areas to enhance recovery rates in those areas that are fished and minimise impacts on seabed habitats (Lambert, Jennings et la. 2014). The fishery could also support cumulative and strategic environmental assessments and systematic planning, collect and share their data to fund participatory monitoring (probably doing this already)

E) Feasibility assessment: Summary

The dimensions considered for this assessment were economic, social, institutional, and technological. Following previous studies (Williams et al., 2021; Booth et al., 2019; Gupta et al., 2020), the guiding questions for each dimension that were addressed for this assessment using available information were:

- Dimension: Economic
    - Are there economic costs and trade-offs expected?
    - Are there any known economic barriers?
- Dimension: Social
    - How is this measure likely to be perceived by fishers?
- Dimension: Institutional
    - What are the human resources required to support implementation of the adaptation option? Is governance support required for this measure, e.g. through new policy? Is the governance or institutional in place a potential barrier for the adaptation of the measure?
    - Does the option require administrative support?
- Dimension: Technological
    - Are the technology and other administrative resources required for the measure available or could feasibly be implemented? Is technological potential for the measure a constraint?

<u>Avoidance: Spatio-temporal closure</u>

- Economic costs and trade-offs: Some areas open to the fishery remain unfished (Cappell et al., 2018) which suggests that additional closures could be established without direct costs to fisheries. No known trade-offs or economic barriers.
- Expected perception of fishers: As closures are already a well-established measure in this fishery, there are no direct losses to fishers expected and overall minimal impact on them is predicted, resistance from fishers is expected to be minimal if the closure is implemented in areas that currently are not being fished as little to no change would be required of them.
- Institutional resources required: Policy required to designate areas as closed areas (e.g. as no-take MPAs) so institutional support is required. This is not expected to be a barrier as closed areas already exist in the area the fishery operates in.

- Technological resources required: There is already a monitoring system which includes a requirement for VMS which could be used to monitor compliance with this measure. The current system could be improved by extending this requirement of VMS to vessels below 10m as well. Additionally, ideally an EM system would be implemented, but this is not essential. Stakeholder engagements might be useful to increase awareness and spread information about why this type of measure is required.

<u>Minimisation: Scallop catch reduction</u>

- Economic costs and trade-offs: This measure would have short-term financial losses to the fishery, but it would follow recent advice from MSS (see in Cappell et al., 2018) to consider implementing measures to protect the target stock. In recent years there has been a trend towards increased landings in the fishery, including additional vessels joining the fishery and increased fishing effort in Scotland (Gov. Scot., 2014). This may leave scope for a reduction in catches. Catch quotas have frequently fluctuated by more than 10% though between years. Additionally, this measure could support the sustainability of the fishery in the long-term although how potential long-term gains compare with short-term losses is unclear.
- Expected perception of fishers: Quota fluctuations of 10% or more are not uncommon in this fishery but this measure is still expected to be met with some resistance from fishers as an increased TAC would have direct economic benefits for the fishery.
- Institutional resources required: Regulatory support from government or local authority required to alter quota allowances in the fishery.
- Technological resources required: Current monitoring system could be used to monitor compliance with this measure. Stakeholder engagements would be useful to increase awareness and spread information about why this type of measure is required.

<u>Remediation: Payment for biodiversity restoration on-site</u>

- Economic costs and trade-offs: This measure would be relatively costly and so a trade-off would be that the fishery could not spend those resources on something else. However, although detailed information was not available, the Shetland scallop fishery produces 65% of the Scottish mussel farming output which is worth a total of 5 million pounds for the local economy (Shetland Leader, 2021) which suggests that the fishery has enough revenues to make a contribution to restoration work.
- Expected perception of fishers: This would be a novel measure so would require change and may result in resistance from fishers to paying.
- Institutional resources required: Policy and administrative support needed to implement this measure and links between the fisheries and local conservation projects or equivalent that would carry out the restoration measures on behalf of the fishery need to be established. The

government could also establish a restoration project in the area to facilitate implementing this measure.

- Technological resources required: Current monitoring system could be used to monitor compliance with this measure. Stakeholder engagements would be useful to increase awareness and spread information about why this type of measure is required.

Compensation: Payments-in-kind

- Economic costs and trade-offs: Fishers may be able to pay in kind, time and knowledge required for this measure, but it should not involve direct economic costs. There are no perceived direct economic barriers to implementing this measure.
- Expected perception of fishers: This would be a novel measure for the fishery so requires change from fishers so this measure may lead to resistance from fishers. However, this measure could take different forms depending on the context so could be adapted to the resources the fishery is able to contribute.
- Institutional resources required: Collaborations with relevant organisations required, but other than that no institutional resources expected to be required for this measure.
- Technological resources required: Current monitoring system could be used to monitor compliance with this measure. Stakeholder engagements would be useful to increase awareness and spread information about why this type of measure is required.

Transformative action 1: Collaborations to drive new more biodiversity-friendly policies

- Economic costs and trade-offs: Time and resources required but no direct economic costs necessarily expected so may be feasible. The fishers may at least be able to contribute some time over a longer period to build these collaborations. No economic barriers identified.
- Expected perception of fishers: No specific issues identified although this is a novel measure for the fishery so may be met with some resistance.
- Institutional resources required: Administrative support required to support this measure as the ultimate goal of the measure is policy passage by local administration of more biodiversity-friendly policies - e.g. a policy for a new status quo of what is required by fisheries in terms of mitigation and compensation of impacts on biodiversity.
- Technological resources required: Online and/or in-person options possible for this measure. Online option would require some technological resources. Stakeholder engagements would be useful to increase awareness and spread information about why this type of measure is required.

Transformative action 2: Share biodiversity goals and strategies with others

- Economic costs and trade-offs: This measure would require some time from but not many other resources. Benefits to fishers could be e.g. market premiums if goals and strategies get shared with markets and consumers.
- Expected perception of fishers: No specific issues identified although there may be some resistance at first as this is a novel measure
- Institutional resources required: Administrative support not expected to be required to support this measure.
- Technological resources required: Online and/or in-person options possible for this measure. Online option would require some technological resources. Stakeholder engagements would be useful to increase awareness and spread information about why this type of measure is required.

Bibliography for appendices

ACAP (2019). *ACAP Review of Seabird Bycatch Mitigation Measures for Demersal Longline Fisheries.* Retrieved from https://www.acap.aq/resources/bycatch-mitigation/mitigation-advice/3240-acap-2017-review-and-best-practice-advice-for-reducing-the-impact-of-demersal-longline-fisheries-on-seabirds/file

Albrecht, J. K. (2013). Taxonomic and functional recovery of epifauna after the permanent closure of an area of the Cardigan Bay Special Area of Conservation (SAC), Wales, to a scallop dredge fishery. MSc thesis, Bangor University, Fisheries & Conservation report No. 28, 81.

Anderson, O., Tracey, D. and Rowden, A. (2019). *Habitat suitability modelling for Protected Corals in New Zealand Waters.* The Department of Conservation, New Zealand. Retrieved from https://www.doc.govt.nz/globalassets/documents/conservation/marine-andcoastal/marine-conservation-services/reports/pop2018-01-finalmethods.pdf

Armsworth, P. R., B. A. Block, J. Eagle and J. E. Roughgarden (2010). The economic efficiency of a time–area closure to protect spawning bluefin tuna. *Journal of Applied Ecology 47*(1), 36-46.

Auster PJ, Malatesta RJ, Langton RW, Watling L Valentine, P.C., Donaldson, C.L.S., Langton, E.W., Shepard, A.N. & Babb, I.G. (1996). The impact of mobile fishing gear on seafloor habitats in the Gulf of Maine (northwest Atlantic): implications for conservation of fish populations. *Rev Fish Sci 4*,185–202.

Baird, S.J. and Mules, R. (in press). *Extent of bottom contact by commercial trawling and dredging in New Zealand waters, 1989–90 to 2018–19.* Deep Water Group. Retrieved from https://deepwatergroup.org/wp-content/uploads/2021/04/Baird-Mules-2020-Trawl-Footprint-1990-2019-DraftFAR.pdf

Baum, J. K., & Worm, B. (2009). Cascading top-down effects of changing oceanic predator abundances. *Journal of Animal Ecology, 78*(4), 699-714.

Booth, H., Squires, D., & Milner-Gulland, E. J. (2019). The mitigation hierarchy for sharks: A risk-based framework for reconciling trade-offs between shark conservation and fisheries objectives. *Fish and Fisheries*, *21*(2), 269-289.

Branch, T.A. (2001). A review of orange roughy Hoplostethus atlanticus fisheries, estimation methods, biology and stock structure. *South African Journal of Marine Science 23*, 181-203.

Bull, B, Francis, R.I C.C, Dunn, A., McKenzie, A., Gilbert, D.J., Smith, M.H., Bian, R. & Fu, D. (2012). CASAL (C++ algorithmic stock assessment laboratory): CASAL user manual v2.30-2012/03/21. *NIWA Technical Report, 135*, 280.

Bradshaw C, Veale LO, Hill AS, Brand AR. (2000). The effects of scallop-dredging on gravelly seabed communities. In: Kaiser MJ, De Groot SJ (eds) Effects of fishing on non-target species and habitats: biological, conservation and socio-economic issues. *Blackwell Science*, Oxford, 83–104.

Bromhead, D., Clarke, S., Hoyle, S., Muller, B., Sharples, P., & Harley, S. (2012). Identification of factors influencing shark catch and mortality in the Marshall Islands tuna longline fishery and management implications. *Journal of Fish Biology*, *80*(5), 1870–1894.

Cappell, R., Keus, B., Addison, J. (2018). *SSMO Shetland inshore brown & velvet crab and scallop fishery.* Marine Stewardship Council Public Certification Reports. Retrieved from https://fisheries.msc.org/en/fisheries/ssmo-shetland-inshore-brown-crab-and-scallop/

CBD (2022). The Kunming-Montréal Global Biodiversity Framework. Conference of the Parties to the Convention on Biological Diversity. Retrieved from https://www.cbd.int/doc/c/e6d3/cd1d/daf663719a03902a9b116c34/cop-15-l-25-en.pdf

Clark, M.R., Bowden, D.A., Stewart, R., Schnebel, K., Quinn, W., Lennard, B., Goode, S.L. and Davis, A. Seamount Recovery: factual voyage report of a survey of seamounts on the Northwest and Southeast Chatham Rise. In press. *New Zealand Aquatic Environment and Biodiversity Report.*

Clark, M.R., Mills, S., Leduc, D., Anderson, O. and Rowden, A.A. (2019). *Biodiversity of Benthic Protection Areas and Seamount Closure Areas: a description of available benthic invertebrate data, and a preliminary evaluation of the effectiveness of BPAs for biodiversity protection*. Fisheries New Zealand. Retrieved from https://fs.fish.govt.nz/Page.aspx?pk=113&dk=24747

Consalvey, M., Mackay, K. and Tracey, D. (2006). *Information review for protected deep-sea coral species in the New Zealand region*. Department of Conservation, New Zealand. Retrieved from https://www.doc.govt.nz/globalassets/documents/conservation/marine-and-coastal/fishing/protected-coralinformation-review.pdf

Cordue, P.L. (2014). *A management strategy evaluation for orange roughy.* ISL Report for Group. Retrieved from https://deepwatergroup.org/wp-content/uploads/2014/08/Cordue-2014-A-Management-Strategy-Evaluation-for-Orange-Roughy.-ISL-Re....pdf

Cordue, P.L. (2019). *A 2019 stock assessment of ORH 7A including Westpac Bank.* Fisheries New Zealand. Retrieved from https://www.mpi.govt.nz/dmsdocument/36921-FAR-201933-A-2019-stock-assessment-of-ORH-7A-including-Westpac-Bank

Corriero A., S. Karakulak, N. Santamaria, M. Deflorio, D. Spedicato, P. Addis, S. Desantis, F. Cirillo, A. FenechFarrugia, R. Vassallo-Agius, J. M. de la Serna, I. Oray, A. Cau, and G. De Metrio. (2005). Size and age at sexual maturity of female bluefin tuna (Thunnus thynnus L. 1758) from the Mediterranean *Sea. J. Appl. Ichthyol.,* 21: 483–486.

Currie DR, Parry GD. (1996). Effects of scallop-dredging on a soft sediment community: a largescale experimental study*. Mar Ecol Prog Ser 134*,131–150.

Currie DR, Parry GD. 1999. Impacts and efficiency of scallop-dredging on different soft substrates. *Can J Fish Aquat Sci 56*:539–550.

Dobby, H., Fryer, R., Gibson, T., Kinnera, S., Turriff, J. and McLay, A. (2017). Scottish Scallop Stocks: Results of 2016 Stock Assessments. *Scottish Marine and Freshwater Science*, *8* (21), 158.

Dulvy, N. K., et al. (2021). Overfishing drives over one-third of all sharks and rays toward a global extinction crisis. *Curr Biol 31*(21), e4773-4787.

DWG (2021). *ORH Harvest Strategy and Harvest Control Rules.* Deep Water Group. Retrieved from https://deepwatergroup.org/wp-content/uploads/2022/03/DWG-2021- Orange-Roughy-Harvest-Strategy-and-Harvest-Control-Rule.pdf.

Esteban, R., et al. (2016). Dynamics of killer whale, bluefin tuna and human fisheries in the Strait of Gibraltar. *Biological Conservation 194*, 31-38.

FAO. (n.d.). *Fisheries Restricted Areas (FRAs)*. Food and Agriculture Organization of the United Nations. Retrieved from https://www.fao.org/gfcm/data/maps/fras/en/

Finucci, B., Edwards, C.T.t., Anderson, O.F. and Ballara, S.L. (2019). *Fish and invertebrate bycatch in New Zealand deepwater fisheries from 1990-91 to 2016-17.* Fisheries New Zealand. Retrieved from https://www.mpi.govt.nz/dmsdocument/34323-AEBR-210-Fish-and-invertebratebycatch-in-New-Zealand-deepwater-fisheries-from-199091-until-201617

Fishbase (n.d. a). *Round sardinella*. Retrieved from https://www.fishbase.se/popdyn/KeyfactsSummary_1.php?ID=1043&GenusName=Sardinella&SpeciesName=+aurita&vStockCode=1059&fc=43

FishBase (n.d. b). *Spiky oreo*. Retrieved from: https://www.fishbase.se/summary/SpeciesSummary.php?ID=9146&AT=spiky%2Boreo

FishBase (n.d. c). *Ribaldo*. Retrieved from: https://www.fishbase.se/summary/Mora-moro.html

FishBase (n.d. d). *Ribaldo*. Retrieved from: https://www.fishbase.se/FieldGuide/FieldGuideSummary.php?genusname=Merluccius&speciesname=australis&c_code=032

FNZ (2020). *Review of sustainability measures for orange roughy (ORH 3B) for 2020/21.*

Fisheries New Zealand. Retrieved from https://www.mpi.govt.nz/dmsdocument/40553/direct

FNZ (2022). Orange Roughy (ORH). *Fishery Assessment Plenary. Stock Assessments and Stock Status.* Fisheries New Zealand. Retrieved from https://www.mpi.govt.nz/dmsdocument/51736-Fisheries-Assessment-Plenary-May-2022-Stock-Assessments-and-Stock-Status-Volume-2-Horse-Mussel-to-Red-Crab

Francis, R.I.C.C. & Horn, P.L. (1997). The transitions zone in otoliths of orange roughy + (Hoplostethus atlanticus) and its relationship to the onset of maturity. *Marine Biology 129*, 681–687.

Frometin J.-M. and J. Powers. (2005). Atlantic Bluefin tuna: population dynamics, ecology, fisheries and management. *Fish and Fisheries, 6*(4),281-306.

Gallagher, A. J., Orbesen, E. S., Hammerschlag, N., & Serafy, J. E. (2014). Vulnerability of oceanic sharks as pelagic longline bycatch. *Global Ecology and Conservation*, *1*, 50-59.

Gladics, A. J., Melvin, E. F., Suryan, R. M., Good, T. P., Jannot, J. E., & Guy, T. J. (2017). Fishery-specific solutions to seabird bycatch in the US West Coast sablefish fishery. *Fisheries Research*, *196*, 85-95.

Glasby, G. P., & Summerhayes, C. P. (1975). Sequential deposition of authigenic marine minerals around New Zealand: Paleoenvironmental significance. *New Zealand journal of geology and geophysics*, *18*(3), 477-490.

Government of Scotland (2014). *Consultation on New Controls in the Scottish King Scallop Fishery.* Retrieved from https://www.gov.scot/publications/consultation-new-controls-scottish-king-scallop-fishery-2014/pages/3/

Government of Scotland (2024). *UK National North Sea Cod Avoidance Plan*. Scottish Government Website. Retrieved from https://www.gov.scot/publications/north-sea-cod-plan/

Greenwood, L., & Eve, P. (2023). *What does biodiversity net gain mean for residential development?* Savills Denmark. Retrieved from https://en.savills.dk/research_articles/352828/319716-0

Guillen, J., Holmes, S. J., Carvalho, N., Casey, J., Dörner, H., Gibin, M., Mannini, A., Vasilakopoulos, P., Zanzi, A. (2018). A review of the European Union landing obligation focusing on its implications for fisheries and the environment. *Sustainability*, *10*(4), 900.

Gupta, T., Booth, H., Arlidge, W., Rao, C., Manoharakrishnan, M., Namboothri, N., Shanker, K., Milner- Gulland, E. J. (2020). Mitigation of elasmobranch bycatch in trawlers: a case study in Indian fisheries. *Frontiers in Marine Science*, *7*, 571.

Helson, J., Leslie, S., Clement, G., Wells, R. and Wood, R. (2010). Private rights, public benefits: Industry-driven seabed protection. *Marine Policy 34*, 557–566.

Horn, P.L. & Ó Maolagain, C. (2019). *A comparison of age data of orange roughy (Hoplostethus atlanticus) from the central Louisville Seamount Chain in 1995 and 2013–15.* New Zealand Fisheries. Retrieved from https://www.mpi.govt.nz/dmsdocument/36384-far-

201929-a-comparison-of-age-data-of-orange-roughy-hoplostethus-atlanticus-from-the-central-louisville-seamount-chain-in-1995-and-201315

Horn, P.L. Tracey, D.M. & Clark, M.R. (1998). Between-area differences in age and length at first maturity of the orange roughy Hoplostethus atlanticus. *Marine Biology 132*(2), 187–194.

ICCAT (2020). Report of the 2020 second intersessional meeting of the bluefin tuna species group. *Collect. Vol. Sci. Pap. ICCAT, 77,* 441-567.

ICES (2022). *Horse mackerel (Trachurus trachurus) in Division 9.a (Atlantic Iberian waters) (Version 1).* ICES Advice: Recurrent Advice. Retrieved from https://doi.org/10.17895/ices.advice.19448030.v1

ISSF (2019). *Non-entangling & biodegradable FADs guide.* Retrieved from https://www.bmis-bycatch.org/system/files/zotero_attachments/library_1/DGMPCGF5%20-%20Non-Entangling-and-Biodegradable-FADs-Guide-2019.pdf

ISSF (2016). Progress summary of 2014–15 ISSF funded marine turtle projects. Washington, DC: ISSF.

Jacob, C., et al. (2016). The effectiveness of the mitigation hierarchy in environmental impact studies on marine ecosystems: A case study in France. *Environmental Impact Assessment Review 60*, 83-98.

Jenkins, S. R., Beukers-Stewart, B. D. And Brand A. R. (2001). Impact of scallop dredging on benthic megafauna: a comparison of damage levels in captured and non-captured organisms. *Mar Ecol Prog Ser, 215*, 297–301.

Lambert GI, Jennings S, Kaiser MJ, Davies TW, Hiddink JG. (2014). Quantifying recovery rates and resilience of seabed habitats impacted by bottom fishing. *Journal of Applied Ecology, 51*,1326–1336.

Leslie, B., Laurenson, C.H., Shelmerdine, R.H., Gear, D.J.R. and Winter, K.A. (2010). Shetland Shellfish Stock Assessments 2010. *NAFC Marine Report, 38.*

Little, A. S., Needle, C. L., Hilborn, R., Holland, D. S., & Marshall, C. T. (2015). Real-time spatial management approaches to reduce bycatch and discards: experiences from Europe and the United States. *Fish and Fisheries*, *16*(4), 576-602.

Mackinson and Daskalov (2007). An ecosystem model of the North Sea to support an ecosystem approach to fisheries management: description and parameterisation. *CEFAS Science Series Technical Report*, *142.*

Mace, P. M., Fenaughty, J. M., Coburn, R. P., & Doonan, I. J. (1990). Growth and productivity of orange roughy (Hoplostethus atlanticus) on the north Chatham Rise. *New Zealand journal of marine and freshwater research*, *24*(1), 105-119.

Marine Scotland (2015). *Scottish Inshore Fisheries Strategy.* Retrieved from http://www.gov.scot/Resource/0049/00494784.pdf

MarLIN. (n.d. (a)). *King scallop*. Marine Life Information Network. Retrieved from https://www.marlin.ac.uk/species/detail/1398

MarLIN. (n.d. (b)). *Edible sea urchin*. Marine Life Information Network. Retrieved from https://www.marlin.ac.uk/species/detail/1311

MarLIN. (n.d. (b)). *Horse mussel*. Marine Life Information Network. Retrieved from https://www.marlin.ac.uk/species/detail/1532

Moreno, G., Salvador, J., Zudaire, I., Murua, J., Pelegrí, J. L., Uranga, J., Murua, H., Grande, M., Santiago, J., Restrepo, V. (2023).The Jelly-FAD: A paradigm shift in the design of biodegradable Fish Aggregating Devices. *Marine Policy*, *147*, 105352.

Minister of Fisheries (2019). *Changes to sustainability measures and other management controls for 1 October 2019.* Retrieved from https://www.mpi.govt.nz/consultations/review-of-sustainability-measures-for-1-october-2019/.

Minister of Fisheries (2023). *Review of sustainability measures for orange roughy (ORH 3B) for 2023/24*. Retrieved from https://www.mpi.govt.nz/dmsdocument/57769/direct

MMO. (2016). *Marking of fishing gear, retrieval and notification of Lost Gear.* UK government page. Retrieved from https://www.gov.uk/guidance/marking-of-fishing-gear-retrieval-and-notification-of-lost-gear

MPI (2013). *National Plan of Action for the Conservation and Management of Sharks*. Ministry for Primary Industries. Retrieved from https://www.mpi.govt.nz/dmsdocument/1138-National-Plan-of-Action-for-the-Conservation-andManagement-of-Sharks-2013

NAFC Marine Centre (2015). A Marine Spatial Plan for the Shetland Islands. Retrieved from https://www.nafc.uhi.ac.uk/research/marine-spatial-planning/shetland-islands-marinespatial-plan-simsp/

Natural England, 2023. *The Biodiversity Metric 4.0 - JP039*. Retrieved from https://publications.naturalengland.org.uk/publication/6049804846366720 661

NOAA (2023). *National Fish Habitat Partnership Projects to Engage Recreational Fishing Communities and Restore Habitat.* NOAA Fisheries. Retrieved from https://www.fisheries.noaa.gov/feature-story/national-fish-habitat-partnership-projects-engage-recreational-fishing-communities-and

PEW (2010). *Conserving Atlantic Bluefin Tuna with Spawning Sanctuaries.* Retrieved from https://www.pewtrusts.org/en/research-and-analysis/reports/2010/10/26/conserving-atlantic-bluefin-tuna-with-spawning-sanctuaries

Phyne, J. G., et al. (2013). Sustainability and the Atlantic Bluefin Tuna: Science, Socioeconomic Forces, and Governance. *Journal of International Wildlife Law & Policy 16*,198-226.

Punt, A., Trumble, R. J., Stern-Prilot, A. (2022) *New Zealand Orange roughy.* Marine Stewardship Council Public Certification Reports. Retrieved from https://fisheries.msc.org/en/fisheries/new-zealand-orange-roughy/

Ramírez-Amaro, S., & Galván-Magaña, F. (2019). Effect of gillnet selectivity on elasmobranchs off the northwestern coast of Mexico. *Ocean & Coastal Management, 172,* 105–116.

Richard, Y., Abraham, E.R. and Berkenbusch, K. (2017). *Assessment of the risk of* *commercial fisheries to New Zealand seabirds, 2006-07 to 2014-15*. New Zealand Ministry for Primary Industries Retrieved from https://docs.niwa.co.nz/library/public/NZAEBR-191.pdf

Richardson, K., et al. (2019). Estimates of fishing gear loss rates at a global scale: A literature review and meta-analysis. *Fish and Fisheries 20*(6): 1218-1231.

Riccioni, G., Landi, M., Ferrara, G., Milano, I., Cariani, A ., Zane, L., Sella, M., Barbujani, G. and Tinti, F. (2010). Spatio-temporal population structuring and genetic diversity retention in depleted Atlantic bluefin tuna of the Mediterranean Sea. *Proceedings of the National Academy of Sciences of the United States of America 107*, 2102-2107.

Ridge, S. A. C. (2021). *Decision document: Inner Dowsing, Race Bank*. Marine Management Organisation. Retrieved from https://assets.publishing.service.gov.uk/media/62569c5fe90e072a03206dcb/Inner_Dowsing__Race_Bank_and_North_Ridge_SAC_Decision_Document.pdf

Robins, J. B., Campbell, M. J., & McGilvray, J. G. (1999). Reducing prawn-trawl bycatch in Australia: an overview and an example from Queensland. *Marine Fisheries Review 61*, 46-55.

Rooker J, Alvarado Bremer J, Block B, Dewar H, de Metrio G, Corriero A, Kraus R, Prince E, Rodríguez-Marín E and Secor D (2007). Life History and Stock Structure of Atlantic Bluefin Tuna (Thunnus thynnus). *Reviews in Fisheries Science*, *15*(4), 265-310.

Rooker, J. R., D. H. Secor, G. De Metrio, and E. Rodriquez-Marin. (2006). Evaluation of population structure and mixing rates of Atlantic bluefin tuna from chemical signatures in otoliths. ICCAT Col. *Vol. Sci. Pap.,* 59, 813–818.

Ruiz J, Martinez de Lagos E, Canive I, et al. (2021) *Electronic monitoring programs conducted by AZTI and DATAFISH in the Spanish tuna fisheries.* Food and Agriculture Organisation of the United Nations. Retrieved from https://iotc.org/documents/WGEMS/01/04

Saunders, G., & Gubbay, S. (2016). *Mussel Beds Modiolus Modiolus on Atlantic sublittoral sediment.* Eionet Forum Retrieved from https://forum.eionet.europa.eu/european-red-list-habitats/library/marine-habitats/north-east-atlantic/a5.62-mussel-beds-modiolus-modiolus-atlantic-sublittoral-sediment/download/en/1/A5.62%20Mussel%20beds%20Modiolus%20modiolus%20on%20Atlantic%20sublittoral%20sediment.pdf

Schopka, S. A., Solmundsson, J., Ragnarsson, S. A., & Thorsteinsson, V. (2010). Using tagging experiments to evaluate the potential of closed areas in protecting migratory Atlantic cod (Gadus morhua). *ICES Journal of Marine Science*, *67*(5), 1024-1035.

Shelmerdine, R. L. (2011). *Catch and habitat mapping of the scallop dredging fishery in Shetland: with a focus on bycatch.* Poster session presented at World Conference on Marine Biodiversity 2011, Aberdeen, United Kingdom.

Shetland Leader (2021). Seafood Shetland and SSMO. Retrieved from: https://www.shetlandleader.org/case-studies/seafood-shetland-and-ssmo

Smith, P.J., Benson, P.G. & McVeagh, S.M. (1997). A comparison of three genetic methods used for stock discrimination of orange roughy, Hoplostethus atlanticus: Allozymes, mitochondrial DNA, and random amplified polymorphic DNA. *Fishery Bulletin 95*(4), 800–811.

Standal, D., Grimaldo, E., & Larsen, R. B. (2020). Governance implications for the implementation of biodegradable gillnets in Norway. *Marine policy*, *122*, 104238.

Stevens, D.W., Hurst, R.J. & Bagley, N.W. (2011). Feeding habits of New Zealand fishes: a literature review and summary of research trawl database records 1960 to 2000. *New Zealand Ministry of Fisheries*. Retrieved from https://docs.niwa.co.nz/library/public/NZAEBR85.pdf

Stewart, B. D., Howarth, L. M., Wood, H., Whiteside, K., Carney, W., Crimmins, É., O'Leary, B. C., Hawkins, J. P., C. M. Roberts, C. M. (2020). Marine conservation begins at home: how a local community and protection of a small bay sent waves of change around the UK and beyond. *Frontiers in Marine Science*, *7*, 76.

Swan, K. D., McPherson, J. M., Seddon, P. J., & Moehrenschlager, A. (2016). Managing marine biodiversity: the rising diversity and prevalence of marine conservation translocations. *Conservation Letters*, *9*(4), 239-251.

Squires, D. and S. Garcia (2018). "The least-cost biodiversity impact mitigation hierarchy with a focus on marine fisheries and bycatch issues." *Conservation Biology 32*(5): 989-997.

Squires, D., Maunder, M., Allen, R., Andersen, P., Astorkiza, K., Butterworth, D., ... & Vestergaard, N. (2017). Effort rights-based management. *Fish and Fisheries*, *18*(3), 440-465.

Taylor, M. D., et al. (2017). Fisheries enhancement and restoration in a changing world. *Fisheries Research 186*: 407-412.

Thunberg, E., Kitts, A., & Walden, J. (2007). A case study of New England groundfish fishing capacity reduction. *Fisheries buybacks*, 239-248. AMES, IA: Blackwell Publishing.

Torres, M. Á., Coll, M., Heymans, J. J., Christensen, V., & Sobrino, I. (2013). Food-web structure of and fishing impacts on the Gulf of Cadiz ecosystem (South-western Spain). *Ecological modelling*, *265*, 26-44.

Ward, E. J., et al. (2009). Quantifying the effects of prey abundance on killer whale reproduction. *Journal of Applied Ecology 46*(3), 632-640.

Werner, T. B., Northridge, S., Press, K. M., & Young, N. (2015). Mitigating bycatch and depredation of marine mammals in longline fisheries. *ICES Journal of Marine Science*, *72*(5), 1576-1586.

Williams, P. A., Simpson, N. P., Totin, E., North, M. A., & Trisos, C. H. (2021). Feasibility assessment of climate change adaptation options across Africa: an evidence-based review. *Environmental Research Letters*, *16*(7), 073004.