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Adapting the Marine Stewardship Council risk-based framework to estimate impacts on seabirds, marine mammals, marine turtles and sea snakes☆

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ABSTRACT

Information available on impacts of fisheries on target or bycatch species varies greatly, requiring development of risk assessment tools to determine potentially unacceptable levels. Seabirds, marine mammals, marine turtles and sea snakes are particularly vulnerable given their extreme life histories, and data are often lacking on their populations or bycatch rates with which to quantify fisheries impacts. The Marine Stewardship Council (MSC) use a semi-quantitative Productivity Susceptibility Analysis (PSA) that is applicable to all species, target and non-target, to calculate risk of impact and to provide a score for relevant Performance Indicators for fisheries undertaking certification. The most recent MSC Fisheries Standard Review provided an opportunity to test the appropriateness of using this tool and whether it was sufficiently precautionary for seabirds, marine mammals and reptiles . The existing PSA was tested on a range of species and fisheries and reviewed in relation to literature on these species groups. New taxa-specific PSAs were produced and then reviewed by taxa-specific experts and other relevant stakeholders (e.g., assessors, fisheries managers, non-governmental conservation organizations). The conclusions of the Fishery Standard Review process were that the new taxa-specific PSAs were more appropriate than the existing PSA for assessing fisheries risk for seabirds, marine mammals and reptiles, and that, as intended, they resulted in precautionary outcomes. The taxa-specific PSAs provide useful tools for true data-deficient fisheries to assess relative risk of impact. Where some data are available, the MSC could consider developing or adapting other approaches to support robust and relevant risk assessments.

1. Introduction

Fisheries directly impact the intended target species - usually fish or invertebrates - as well as non-target or bycatch species, which may include seabird, marine mammal, marine turtle or sea snake species which are caught incidentally [1]. The information available on fisheries impacts varies greatly across species and fisheries, so risk-based assessment methods have been developed to help address this data gap (e.g., [2,3], [4], [5], [6]. Risk assessment methods can provide explicitly defined criteria to assist fisheries managers identify whether a bycatch problem exists, the magnitude of the problem, and whether specific management objectives are being achieved (see examples in [7],

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[8], [9]. These methods can range from qualitative assessments based on expert judgement, for example the Scale Intensity Consequence Analysis (SICA) as applied in the Australian Ecological Risk Assessment for the Effects of Fishing (EREAF) [3], to fully quantitative impact assessments, for example using population models [10-14].

Marine birds, mammals and reptiles share some life-history characteristics, such as long lifespans or low reproduction, that can make them particularly vulnerable to anthropogenic pressures; direct mortality from fisheries is often one of the main threats to their long-term population viability [15-20]. Although work in recent decades has advanced our understanding of the threats of bycatch for these species groups, critical knowledge gaps remain in terms of estimating bycatch mortality during fishing operations and in determining impacts at the population level [21].

The updated Marine Stewardship Council (MSC) Fisheries Standard v3.0 requires that impacts of the fishery under assessment are evaluated with respect to the likelihood of hindering recovery of bird, mammal or reptile species to favourable conservation status, defined as a level of at least 50% of carrying capacity [22] [23]. Ideally this requires independent, quantitative assessments of this impact. Where these assessments are not available application of the MSC Risk-Based Framework (RBF) is required, following a process previously set out in the Fisheries Certification Process (FCP). The RBF uses a semi-quantitative Productivity Susceptibility Analysis (PSA) adapted from the method developed for the Australian EREAF to generate a risk score and equivalent MSC score for each non-target species that interacts with the fishery [24]. The PSA assumes that risk is based on the inherent productivity of a species and the susceptibility of the species to fishing activities [2]. Each of the productivity and susceptibility components is quantified separately using a scoring system based on demographic information and characteristics of the species and gear that reflect likelihood of capture or mortality. This scoring is based on the literature or from stakeholders with knowledge of the species or fishery [24]. The risk score for each attribute is based on defined threshold values in the relevant productivity and susceptibility tables.

The threshold values for scoring productivity attributes as low, medium or high were originally developed for the EREAF by considering a range of values for the taxa (mainly fish but also including some birds, mammals and reptiles) and fisheries in Australia. The MSC recognized that further development was required on the PSA for application for fisheries and taxa globally [24]. Stakeholder feedback prior to the commencement of the current Fisheries Standard Review indicated that the MSC PSA within FCP v2.2 (hereafter "PSA v2.2") is not always delivering its intent of consistent, precautionary, and robust outcomes aligned with the MSC Fisheries Standard. As part of a wider project to review the MSC Risk-Based Framework the objective of this study was to determine which PSA attributes and thresholds are most appropriate and precautionary for assessing fishery impacts on birds, mammals, and reptiles in the context of the MSC certification process. The selected attributes and defined thresholds were then used to revise the PSA methodology as needed for these species groups. Alongside the revisions, the process for the PSA was moved to a new scheme document called the MSC Fisheries Standard Toolbox (hereafter "PSA v3.0") to better reflect its position as a tool supporting the application of the MSC Standard.

The PSA is a widely used tool in management systems globally (e.g., [7]. As such, results and conclusions presented here are also relevant for assessment of bycatch risk in other management contexts. The concepts behind the PSA and the Productivity attributes developed here could also be used for risk assessments of other anthropogenic impacts, including from offshore hydrocarbon exploration or production (e.g. [25], [26], or marine renewables developments such as wind farms (e.g. [27], [28]).

2. Evaluation of PSA v2.2

The PSA attributes and thresholds used in the PSA v2.2 are provided in Supplement 1. Once scores for individual productivity and susceptibility attributes are assigned, the productivity attribute scores are averaged to provide an overall productivity score (P) for the species, and the susceptibility attribute scores are multiplied and rescaled to the interval [1 3] to provide a susceptibility score (S) [24]. Overall risk (R) is calculated as $R=\sqrt{(P^2+S^2)}$.

There is a direct quadratic relationship between R and the MSC Performance Indicator (PI) score equivalents, represented by the equation: MSC PI score $= -11.965(R)^2+32.28(R)+78.259$ [24]. The MSC PI score is presented as a whole number within the range of 0–100. In an MSC fishery assessment, scores of <60 result in a fail, scores of 60–79 would result in the fishery passing but with a condition to make improvements, and a score of ≥80 would result in a fishery passing with no conditions [24].

The appropriateness of the PSA v2.2 was evaluated through a combination of testing, literature review, expert review and public consultation.

2.1. Testing PSA v2.2

When the Fisheries Standard Review commenced in 2018 there was only one MSC-certified fishery that had applied PSA v2.2 for birds, mammals or reptiles. A review of this assessment report and initial testing of PSA v2.2 on a selection of eight species-fishery interaction scenarios revealed issues with lack of clarity in the requirements that could lead to inconsistent, and in some cases inappropriate, results (Table 1).

In addition, a specific study of whether the MSC PSA was an appropriate tool for assessing the risk of direct impacts of fisheries on seabirds showed that the current MSC PSA was not appropriate or precautionary when applied to those taxa [29].

2.2. Literature review

The lead author conducted a literature review and trial testing for a sample of species on the appropriateness of productivity attributes and thresholds, and especially whether they reflected the life-history characteristics of the species group, distinguished between species within the group, duplicated other attributes or were precautionary [30]; adapted in Supplement 1. The most appropriate productivity attributes in the PSA v2.2 for these species groups were age at maturity, maximum age and fecundity, noting that some changes could be made to specific attributes to improve their applicability to species groups. The PSA v2.2

Table 1
Issues with appropriateness & precaution identified in a review of application of PSA v2.2 in an MSC certified fishery and eight species-fisheries scenarios.

PSA v2.2 attribute	Issue(s) identified
Age and size productivity attributes	No instruction provided on what value to use when a range is presented, e.g., using most precautionary value.
Areal overlap	No instruction provided on whether global distribution of species or seasonal or population-specific distributions should be applied.
Encounterability	No instruction provided on how to score air-breathing animals such as birds, mammals and reptiles. For example, Hobday et al. [3] provides instructions that these species should be scored as "high risk" as they will always have a risk of encountering the gear during setting and hauling.
Selectivity	Thresholds pertain to capture of species at size < maturity, but for birds, mammals and reptiles it is generally more appropriate to consider captures of adults.

susceptibility attributes of availability, encounterability, fishing-gear selectivity and post-capture mortality were considered appropriate, but thresholds generally needed modification. For example, for the susceptibility attribute of areal overlap, many species within these groups are highly migratory (e.g., marine mammals, seabirds, marine turtles), so the year-round population distribution does not provide an adequate indication of risk during specific periods such as breeding or wintering [31-33].

An analysis of attributes used in other species-specific PSAs indicated that some productivity attributes specific to species groups would be more appropriate for revising PSA v2.2 [30]. For example, fecundity could better capture elements of life-history strategy. These included frequency of breeding for birds and mammals and mean clutch size per nest, female or season, and remigration interval for marine turtles [34-37,33]. Attributes that better reflect catchability of species groups could be incorporated into the scoring of susceptibility, for example using a selectivity matrix compiled by experts and considering morphological and behavioural aspects, as was carried out for cetaceans (see [35,36]).

2.3. Expert review and consultation

In March-April 2021, five experts with knowledge of the species groups and fishery interactions were commissioned to review the attributes and potential improvements, considering a range of species within the species group and potential interactions with different fisheries. A template was developed to collect information on the clarity, relevance and information availability for the attributes.

It was noted that not all productivity attributes are relevant as indicators of productivity (e.g., trophic level) and that some may duplicate the same signal from another indicator (e.g., size and age could be correlated). It was suggested that those attributes that are less relevant and potentially overlap be removed, focussing on using information on age instead of size where possible. There was general agreement that, although results for most species were precautionary, thresholds were not useful to identify differences in life-history characteristics within a species group. For example, all seabirds and marine mammals scored high risk for fecundity despite key biological differences in number and frequency of offspring produced.

Experts were asked to review if each of the existing susceptibility attributes were relevant as an indicator to estimate susceptibility of the species group (seabirds, marine mammals, marine turtles, sea snakes). Four of five experts agreed that areal overlap and encounterability attributes were essential indicators of risk for direct impacts of fisheries on these species' groups, with the marine mammal expert noting that these were useful indicators only when used in combination with the others, as fisheries can have high overlaps with some marine mammal species but no interactions.

The experts were also asked to consider the application of a revised approach for scoring encounterability through scoring birds, mammals and reptiles at default high risk unless effective mitigation measures were applied, which would reduce the scores. All five experts considered this a useful approach, but two experts suggested that guidance should be developed specifying when and how scores should be reduced.

For selectivity, all five experts agreed that this was an important attribute but needed refinement. Experts were asked to consider the inclusion of a susceptibility matrix adapted from the Monterey Bay Aquarium Seafood Watch standard [38] to score selectivity for specific species and gear interactions but all five experts commented that the species-gear interaction scores in the matrix did not adequately account for regional differences. Four of five experts indicated that the post-capture mortality susceptibility attribute was essential, with one expert commenting that it was a useful attribute but perhaps less important than the others.

Based on the expert feedback, three options were proposed to the MSC: (1) further refine current attributes based on expert feedback; (2) select a sub-set of more appropriate and less overlapping attributes; or (3) redefine productivity attribute thresholds to allow for more differentiation within the species group. These options were not mutually exclusive.

The proposed changes to the Fisheries Standard as a whole, including some minor changes proposed to the PSA v2.2 for birds, mammals and reptiles, were circulated as part of a public stakeholder consultation in February-April 2022 via an online survey (see [39] for methodology). There were 23 respondents to the survey on the PSA requirements [40]. In line with the expert feedback, the main stakeholder concerns were that further refinement was required to ensure that attributes and thresholds were biologically applicable for the species groups and that implementation should be standardised and repeatable.

Pilot testing was carried out throughout the review process, where auditors trialled the proposed requirements to assess how they work in practice. Feedback indicated that the PSA v2.2 was inappropriate for assessing birds, mammals and reptiles due to the unsuitability of taxa-specific thresholds (e.g., fecundity required an assessment of number of eggs produced when referring to mammals).

The overall conclusion of the evaluation was that PSAv2.2 needed to evolve in order to better represent the risks to bird, mammals and reptiles. It was proposed that changes be made to improve the appropriateness of the attributes and thresholds based on current knowledge of the biology and behaviour of these species groups relative to their vulnerability to fishing effects. These conclusions were reviewed by the MSC Technical Advisory Board and Stakeholder Advisory Council, and a decision was made to develop bespoke productivity tables per taxa and refine susceptibility attributes.

3. Development of PSA v3.0 for birds, mammals and reptiles

3.1. Taxa-specific productivity attributes

For the revision of the productivity analysis, three attributes for each species group were proposed initially: age at maturity, maximum age and fecundity. Given the contrasting life history of marine turtles and sea snakes, the reptile group was split into two productivity tables to better capture the differences in demography. Also, for sea snakes, length was used instead of age categories, reflecting the relative paucity of age-specific data.

The MSC commissioned experts on the specific species groups to undertake a review of the proposed attributes and develop thresholds. The draft thresholds for each species group were then peer reviewed by two experts. Peer review comments were considered by the consultants and either changes were made, or the comment was rejected and a rationale was provided.

For each species group (birds, mammals, marine turtles and sea snakes) experts developed thresholds by applying the methodologies described in Supplement 2 (which includes data for >100 taxa and supporting references) and summarised below. First, data were collected on a sample of species or populations within each species group that covered the range of possible values for each attribute. For seabirds, a sample was taken from the 359 extant species of seabird organised by functional group as provided in Dias et al. [15]. The sample was either 30% of species within a functional group or one sample taken from each genus within the group, whichever was higher, resulting in 120 species being selected. All marine mammal species and marine turtle Regional Management Units (RMUs) were sampled. For sea snakes, the sample was primarily the genera *Aipysurus* and *Hydrophis*, as they are recorded most frequently as bycatch in trawl and coastal fisheries, but a selection of species from *Laticauda* and *Acrochordus* species were also included, which summed to a total of 15 species.

Data were collated for each sample species on age at first breeding, maximum age and fecundity. A literature review was conducted focusing on synoptic references that compile and present values for productivity attributes for different species or RMUs, as well as specific references that provided such information. To the extent possible, ranges of values were included for each attribute and then a single best value, generally an average provided in the reference, was selected.

There was consensus among experts across all taxa that insufficient information was available for the attribute of maximum age, so it was agreed that this attribute would be removed. For marine turtles, four options were considered for the fecundity attribute considering different combinations of metrics, e.g., using eggs per season vs hatchlings per season or remigration interval, and whether this should be calculated for the complete reproductive lifespan of females.

For seabirds, marine turtles and sea snakes, once the data were collated, the low/medium/high risk thresholds for each attribute were plotted to determine distributions within and among species or RMUs. Thresholds were intended to be the 'medium' values, to reflect the mean distributions, and for 'low' and 'high' values to reflect the mean ± 1 SD. For seabirds, the exception was the fecundity category, where a category approach of <1 egg/year, 1 egg/year and >1 egg/year was most selected as appropriate given the skewness of the distribution.

For marine mammals, to best ensure that the resulting thresholds would be appropriate for all species, the overall mammal group was split into three distinct categories: 1) mysticetes, sperm whales and sirenians; 2) odontocetes (excluding sperm whales); 3) pinnipeds and sea otters. The approach to designating thresholds was the same as for seabirds, marine turtles and sea snakes for these marine mammal categories except for the mysticetes, sperm whales and sirenians, where the mean and interquartile range of the distribution were used to set the thresholds rather than ± 1 SD this gave more reasonable results given the skewness of the parameter distributions.

After the thresholds were defined, an overall productivity score for each species in the sample was calculated. The results were groundtruthed using demographic information or known information on maximum population growth to ensure that the results were both appropriate and provided reasonable differentiation between species or populations (see Supplement 2, noting that this also includes the data and references for the sampled taxa used to develop these thresholds).

Draft thresholds were peer reviewed by two experts on each taxon. The peer reviewers were provided with a template requesting their input on whether the results of the productivity analysis were appropriate given life-history characteristics and inherent growth rates of species within the species group. For marine mammals, they were also asked to comment on the appropriateness of splitting the mammal group into smaller categories. For marine turtles, reviewers were asked to provide feedback on the fecundity metric that would be most appropriate. After the peer review the attributes or thresholds were updated as necessary.

The main revisions following peer review were to the bird, pinniped and sea snake productivity tables. For birds and pinnipeds, an attribute was added on 'optimal' adult survival. 'Optimal' adult survival represents what the species is capable of achieving naturally (i.e. without human mortality) in healthy, stable populations. As peer reviewers noted, this is an important metric when calculating the overall population growth rate represented by the productivity attributes. However, for other marine mammals, marine turtles and sea snakes the published adult survival rates were not deemed appropriate because they were either derived from unstable or declining populations or survey methods and length of studies (i.e., photographic mark-recapture) that did not yield reliable 'optimal' adult survival estimates. For the birds and pinnipeds, instruction was added to ensure that 'optimal' adult survival was used and that where a species is in decline due to anthropogenic impacts, alternatives from other unaffected species that are similar taxonomically and ecologically should be used, or, if data are not available, a score of high risk is assigned. The method used to develop the thresholds for optimal adult survival for birds and pinnipeds was similar to that for other attributes, including collecting best available data (mean value from studies or a modelled value) for sample species and setting thresholds based on ±1 SD from the mean. Data were collected on 'optimal' adult survival rates for the sample of species (120 birds, 24 pinnipeds and 1 sea otter).

For pinnipeds and sea otters, the fecundity attribute was also revised. Instead of using the 1/inter-birth interval, that is the norm for cetaceans, the average annual reproductive rate (birth rate or pregnancy rate) is used to account for synchronized annual breeding cycles based on delayed implantation that are common to many pinniped species. The data were collated for 25 species (24 pinnipeds, 1 sea otter) from the literature, the best available value was used, and thresholds set based on ±1 SD from the mean.

The fecundity attribute was selected for sea turtles following peer review based on it having best data availability. It was defined using the equation Fecundity (F) = $[E^*C]/RI$ where E is eggs per clutch per female per season, C is clutches per female per season and RI is remigration interval. For sea snakes, in response to peer-reviewer comments on the extra level of precaution needed for this group as very little information is available, the fecundity attributes were revised so that there is no longer a 'low' category – only medium and high categories. The draft final PSA was reviewed by the MSC Technical Advisory Board (TAB) and Stakeholder Advisory Council (STAC) and no changes were made.

3.2. Refined susceptibility attributes

The PSA v2.2 susceptibility attributes (areal overlap, encounterability, selectivity and post-capture mortality) were refined based on outputs from the literature review, pilot testing and expert review, to provide guidance on how the attribute should be scored for birds, mammals and reptiles. Guidance was added to areal overlap so that seasonality of the species distribution was considered and the period with highest potential overlap with fishing effort was used for scoring. For encounterability, guidance was added that when considering impacts of active gears or gears set within the diving range of the species that the default score is high risk but allowing adjustment to a lower score if the fishery applies mitigation measures to reduce encounterability (medium risk) or there is independently verified data that the fishery has minimised catch of this species to zero or negligible levels (low risk). The MSC Fisheries Standard v3.0 defines 'negligible' for birds, mammals, reptiles and amphibians where the average estimates of mortality from the fishery are less than 10 individuals per year (based on adequate information to estimate the impact of the UoA on the species) and the lower bound of the estimated breeding population size is equal to or greater than 5000 individuals [23]. The guidance added to the selectivity attribute was similar; it started at high risk and reduced risk with evidence available of bycatch mitigation or negligible bycatch levels. The post-capture mortality also requires applying a high risk score unless there is evidence that the majority of species are released, with no injuries, and able to survive in 30–70% (medium) or >70% of interactions (low risk).

The only changes made to thresholds were for the selectivity attribute where the reference to individuals less than the size of maturity was removed. Instead, the thresholds indicate that, if encountered, individuals are rarely (<5% deployments), regularly (5–50% deployments) or frequently (>50% deployments) caught or impacted. The reference to impact as well as capture is also included so that issues such as seabird strikes of warp cables (where no capture occurs) are also adequately considered.

3.3. Calibration of revised PSA with default assessment tree

The draft final PSA was calibrated with the new Fisheries Standard v3.0 default tree. In September 2022, three consultants were contracted to carry out scoring of the PSA and the Performance Indicator that the fishery would be scored against if the MSC Fisheries Standard v3.0 was used instead of the PSA (i.e., situations where the species has an independent, quantitative assessment relative to Favourable Conservation Status). This is the ETP and Out-of-Scope Species (OOS) Outcome Performance Indicator. The OOS species are birds, mammals, reptiles and amphibians, designated as such because they are ineligible to carry the MSC ecolabel. This testing used information in the assessment reports and other publicly available sources to determine if the PSA results were appropriate and precautionary. As the scores derived from the MSC PSA were calculated using a quadratic equation, the values were rounded to the nearest whole number. In contrast, scores are assigned in the default assessment tree by category, i.e., results are recorded as <60; 60; 80 or 100. Because of this difference in approaches, the level of precaution was evaluated with respect to whether the results of the PSA testing were in the same scoring category as the default tree, or a less or more precautionary scoring category. As described in Section 2, the scoring categories are as follows: <60; 60–79; ≥ 80.

Most PSA scores from the testing were within the same scoring category or a more precautionary scoring category as the initial scores, and only one PSA score was less precautionary (Table 2).

4. Final PSA for birds, mammals and reptiles

PSA v3.0 includes separate productivity tables for birds, mysticetes and sirenians, odontocetes, pinnipeds and sea otters, marine turtles and sea snakes [41], Table 3). When scoring productivity attributes, it is also required to use the mean or median value, if available, or if a range is provided, to use the most precautionary value in the range. Proxies can be used to score attributes only if information is available for closely related species with similar demographic traits. If information is not available to score an attribute and an appropriate proxy is not available, the score defaults to high risk (3) for that attribute [41].

A single susceptibility table for birds, mammals and reptiles is used (Table 4). Default scores of high risk are required for encounterability and selectivity for all air-breathing species, which may be reduced if measures expected to minimise mortality are in use (reduce risk score by one, e.g. from 3 to 2), or if it has been demonstrated that bycatch of the species has been reduced to zero or negligible levels in the fishery, consistent with definitions in the revised Fisheries Standard v3.0 [22].

5. Discussion

The new Fisheries Standard v3.0 has improved the scoring system used to evaluate whether a fishery seeking certification is likely to hinder recovery of a bird, mammal or reptile species. It uses a new threshold, termed *favourable conservation status*, set at a minimum level of 50% carrying capacity [22] [23]. The Fisheries Standard v3.0 is focussed on the evaluation of the impacts of the fishery under assessment and also includes new requirements to ensure that the fishery minimises its mortality of birds, mammals and reptiles [22]. It is acknowledged that the cumulative threats would ideally be considered for many of these species groups, but there is not yet enough information available that would allow proportional impacts of each MSC fishery relative to the wider impacts to be assessed. This issue is discussed in more detail in Good et al. [22]. It is noted that the development of PSA v3.0 has focussed on ensuring that there is sufficient precaution in the assessment of risk of impact when data are limited. This should better ensure that fisheries which achieve a positive outcome are having low or no impacts on birds, mammals or reptiles. Future development of the risk assessment framework could focus on data-limited means of conducting such proportional impact assessments.

Information to support quantitative impact assessments of fisheries are often lacking for birds, mammals and reptiles [21,42,17]. The MSC requires that where the population status of the bird, mammal or reptile is unknown, or where the direct impacts of the fishery on the species has not been determined quantitatively with respect to the favourable conservation status reference point, that the risk-based framework is used [41]. The lack of quantitative assessments for these species will likely increase use of the risk-based framework in MSC assessments, which highlights the importance of having appropriate and precautionary tools, such as a PSA, to estimate risk of impact to ensure that the MSC certification program is accessible to all fisheries globally, regardless of size and scale.

In addition to incorporating precaution, the objective of the PSA is to strike a balance between making thresholds more detailed and taxonomically appropriate and not making them too onerous with respect to available information. For example, attributes on maximum age or reproductive lifespan were not included in the PSA v3.0 because there was not enough reliable information to develop these at the time. If data become available in future, the PSA can be updated accordingly. The reduction in number of productivity attributes from seven to two or three per species group will improve efficiency and avoid over-parameterisation of the PSA, an issue which was shown in one study to reduce accuracy of risk results [43]).

The inclusion of the PSA v3.0 within the MSC Fisheries Standard Toolbox will allow for regular review and, where needed, updating of the methods. With that in mind, future developments of the PSA could include ideas generated here through the expert input and peer review process that were not taken forward. For example, although the experts agreed that the selectivity matrix proposed in earlier options was not developed at a scale that would make it useful, relevant matrix-style approaches could be developed in the future to assist assessors with scoring fisheries.

Another consideration is that the 'high productivity / low risk' category within the productivity attributes contrasts with the understanding that birds, mammals and reptiles generally have low population growth rates relative to many other non-target species encountered in fisheries. This is one issue with having taxonomically-specific resolution for productivity scoring, i.e., with relative risk assessments when sub-dividing species into small groups the risk is only relative within the group. This may lead to underestimates of risk for species on the low productivity end of the spectrum within the species group. One way to solve this would be to remove the 'high productivity / low risk' threshold altogether for productivity attributes for birds, mammals and reptiles and consider differences within species groups within the 'medium productivity/ medium risk' or 'low productivity / high risk' categories only, as has been conducted with the sea snake group in PSA v3.0. A similar approach could also be considered for other species groups with low resilience to fishing pressure, such as some sharks. Another way to address this would be to assess absolute risk rather than relative risk.

In a strict sense, "productivity" is the average number of offspring produced per adult female in a year. For birds, mammals and reptiles,

Table 2
Calibration results for final PSA option with default tree for species groups.

Species group	No. PSA evaluations (species/fishery combinations)	No. same scoring category (%)	No. where PSA is more precautionary (%)	No. where PSA is less precautionary (%)
Birds	9	0 (0%)	9 (100%)	0 (0%)
Mysticetes	9	8 (89%)	1 (11%)	0 (0%)
Odontocetes	13	8 (62%)	5 (38%)	0 (0%)
Pinnipeds	6	4 (67%)	2 (33%)	0 (0%)
Marine turtles	11	5 (45%)	5 (45%)	1 (10%)
Sea snakes	5	4 (67%)	1 (33%)	0 (0%)
TOTAL	**53**	**29 (55%)**	**23 (43%)**	**1 (2%)**

Table 3
PSA v3.0 productivity scores and attributes for birds, mammals and reptiles (adapted from [41].

Productivity Attribute	High productivity (low risk, score = 1)	Medium productivity (medium risk, score = 2)	Low productivity (high risk, score = 3)
Birds			
Average age at first breeding *Where there are studies of only short duration used to estimate this, it is appropriate to consider whether the species value is anomalously low for the genus and score based on what is the norm for the genus rather than the individual species.*	<2.7 years	2.7–6.9 years	>6.9 years
Average 'optimal' adult survival probability *Use the optimal average adult survival probability values, if available. The optimal value represents what the species is capable of achieving biologically with healthy, stable populations, i.e. the value is not unsustainably low due to population decline driven by anthropogenic impacts. If a species is in decline due to anthropogenic impacts, alternatives from other unaffected similar species should be used.*	<0.81	0.81–0.94	>0.94
Fecundity *Considers both the maximum number of chicks per breeding pair, and the frequency of breeding.*	>1 chick/year	1 chick/year	<1 chick/year
Mysticetes & sirenians			
Average age at maturity *Age at female sexual maturity in years.*	<6	6–8	>8
Fecundity *Use 1/inter-birth interval (IBI)*	>0.40	0.30–0.40	<0.30
Odontocetes			
Average age at maturity *Age at female sexual maturity in years.*	<6	6–11	>11
Fecundity *Use 1/inter-birth interval (IBI)*	>0.58	0.23–0.58	<0.23
Pinnipeds & sea otters			
Average age at maturity *Age at female sexual maturity in years.*	<5	5–7	>7
Fecundity *Use average annual reproductive rate (birth rate or pregnancy rate).*	>0.87	0.58–0.87	<0.58
Average 'optimal' adult survival probability *Use the optimal average adult survival probability values. The optimal value represents what the species is capable of achieving biologically with healthy, stable populations, i.e. the value is not unsustainably low due to population decline driven by anthropogenic impacts.*	<0.84	0.84–0.94	>0.94
Marine turtles			
Average age at maturity *Age at female sexual maturity in years.*	< 15	15–25	> 25
Fecundity: Eggs per season per remigration interval *Calculated as: (number of eggs per nest x number of nests per season) / remigration interval. Where ranges are provided, the most precautionary value shall be adopted for scoring.*	> 150	100–150	< 100
Sea snakes			
Average length at maturity (cm) *Median or mean length at maturity.* *Use snout vent length, as this is most often recorded*	<61.5	61.5–109.0	>109.0
Average maximum size (cm): *If differences in size between sexes, use more precautionary value. Use snout vent length, as this is most often recorded*	<90.4	90.4–168.3	>168.3
Fecundity: *Egg-laying: annual reproductive output should be calculated as: number of eggs per clutch / number of nests per year.* *Live bearing: clutch size / number of years between reproductive periods.* *No species are categorised as 'low' risk/ 'high productivity'*	N/A	>5	≤5

however, productivity alone is not sufficient to evaluate whether the fishery is likely to hinder recovery of a species to favourable conservation status. The PSA uses the term "productivity," but the attributes selected actually relate to population growth rate. For example, the expansion of the PSA v3.0 to include 'optimal' adult survival for seabirds and pinnipeds reflects this. In future estimates of intrinsic or maximum population growth rate could be used either as an attribute (as it is for the PSA for assessing US fish stocks in [44] or to replace the attributes with population growth rate; however, data limitations mean that this approach may not be applicable in all situations.

Although the susceptibility attributes as developed by Walker [6] and applied by Hobday [3] and in PSA v2.2 and 3.0 cover many of the elements that contribute to individual mortality of a species, the scale of the impact is not considered. Since the method does not account for the level of fishing effort involved, it could over- or under-estimate a species susceptibility to capture. Considering an attribute or method to scale susceptibility scores by fishing effort could resolve this issue in future, as could moving closer to measuring absolute risk rather than relative risk.

Hobday et al. [2,3] developed the PSA to assess the relative risk that fishing activities cause an unacceptable change to the population dynamics of the species in question. The PSA has been applied globally to both target and bycatch species (see examples in [7], [43]. PSAs have also been developed for specific species groups (e.g. birds, mammals or turtles) [34-36], [45], [37], [46], [13], [47], but this is the first time that different PSAs for each taxa have been included in the MSC RBF. The PSA is most useful to evaluate the relative risk of fisheries impacts on species and, as it includes a method to allow experts to provide information when published data are unavailable, is well adapted for a data-poor environment [29]. It also has an advantage in being relatively rapid compared with developing and running full population models [4].

In the PSA, thresholds were selected that spread species along a productivity scale, from low to high productivity, rather than providing an absolute value reflecting productivity of a particular species [47]. However, the relative risk has to be converted into absolute risk, as the latter is required by the MSC assessment process. Issues with the success

Table 4
PSA v3.0 susceptibility attributes for birds, mammals, reptiles and amphibians [41].

Susceptibility Attribute	Low susceptibility (low risk, score = 1)	Medium susceptibility (medium risk, score = 2)	High susceptibility (High risk, score = 3)
Areal overlap (availability): *Overlap of the fishing effort with a concentration of the ETP/OOS unit. The team shall consider seasonality in ETP/OOS unit distribution (e.g. use non-uniform density or occurrence maps in preference to static range maps). The team shall adopt a precautionary approach and base the score on the highest potential overlap with the fishing effort. If information on seasonal distribution is not available, for land-nesting species (e.g. birds, turtles, pinnipeds) the team shall consider whether the fishery operates in proximity to breeding colonies at the time of breeding as well as information on the foraging radius and / or habitat preference for breeding and non-breeding ETP/OOS units to determine an areal overlap score.*	<10% overlap	10–30% overlap	>30% overlap
Encounterability: *The position of the ETP/OOS unit within the water column relative to the fishing gear, and the position of the stock/species within the habitat relative to the position of the gear. The team shall assign a default high risk score for all air breathing species for active gear or gear set within the diving range of the species. The team may adjust this default score if mitigation measures that reduce encounterability with the gear are in place and are shown to be effective at reducing bycatch. The team may adjust the score as follows:* *• The team may reduce the score from 3 to 2 if the fishery applies mitigation measures to reduce encounterability that are likely to work, based on use of accepted best practice or if bycatch has been minimised when applying equivalent measures in a similar fishery.* *• The team may reduce the score from 3 to 1 if there is independently verified data that the fishery has minimised bycatch to zero or negligible levels.* *Measures that reduce encounterability include those that reduce the opportunity for the species to interact with the gear, (e.g. that reduce attraction to the gear, reduce ability to reach gear through scaring techniques, improve visibility of gear).*	Low overlap with fishing gear (low encounterability).	Medium overlap with fishing gear.	High overlap with fishing gear (high encounterability).
Selectivity of gear type: *Potential of the gear to retain species. The team shall score all air breathing species as default high risk based on the likelihood that, if encountered, individuals are frequently caught or impacted (given that in some cases, a species may not be caught but still injured or killed by the gear). If there are proven effective mitigation measures to reduce selectivity of the gear type, the team may reduce the score by one risk level.* *• The team may reduce the score from 3 to 2 if the fishery applies mitigation measures that are likely to work to reduce selectivity if gear is encountered, based on use of accepted best practice or where bycatch has been minimised when using equivalent measures in a similar fishery.* *• The team may reduce the score from 3 to 1 if there is independently verified data that the fishery has minimised bycatch to zero or negligible levels* *• The team may reduce the score from 3 to 1 if there is independently verified evidence that the species is not caught in the gear, regardless of whether mitigation measures are applied.* *Measures that reduce selectivity, if encountered, include changing size or shape of gear to reduce ability to retain or impact species or including escape options from gear.*	If encountered, individuals are rarely (i.e., in less than 5% of deployments) caught / impacted.	If encountered, individuals are regularly (i.e., in 5–50% of deployments) caught / impacted.	If encountered, individuals are frequently (i.e., in more than 50% of deployments) caught / impacted.
Post-capture mortality (PCM): *The chance that, if captured, a species would be released and that it would be able to survive. For all air breathing species the team shall assign a default high risk score unless independent verified observations demonstrate that individuals are released alive and post-release survivorship is high. If there is evidence that the majority are released post-capture, with no injuries, and able to survive (>66% of interactions), the team may assign a low risk score. If there is evidence that some are released post-capture with minor injuries but able to survive (33–66% of interactions), the team may assign a medium risk score. If the majority are dead or injured (>66% of interactions), the team shall assign a high risk score.*	Evidence of majority released alive post capture and survival. >66% of animals are returned alive and survive the encounter. If observers can verify that >66% are released alive in combination with a high risk score for selectivity, the team may reduce the PCM score to a low risk score (1).	Evidence of some released alive post capture and survival. 33–66% of animals are returned alive and survive the encounter. If observers can verify that 33–66% are released alive in combination with a high risk score for selectivity, the team may reduce the PCM score to a medium risk score (2).	Retained species or majority dead or low probability of survival when released.

of the PSA in correctly assigning an absolute risk score, as highlighted in Hordyk and Carruthers [43], may be further compounded by this conversion. Calibration testing was conducted between the MSC scores and PSA scores as described in Section 3.3. However, there are currently few absolute risk assessments in fisheries that are currently MSC-certified to use for calibration. For example, for the seabird group, the samples were taken from one fishery which had a high overlap with seabird species with naturally low productivity, which likely reflects why the results were more precautionary than for other species groups, where samples were taken from a wider range of fisheries. As better demographic and fishery-specific information becomes available for these species groups, and more absolute risk assessments are conducted, further calibration should be undertaken.

A gap exists between the relative risk assessment of the PSA and the fully quantitative assessment required in the Fisheries Standard v3.0. Tools to help data-limited fisheries assess their impacts already exist and new developments are regularly occurring. For example, the Spatially Explicit Fisheries Risk Assessment adopted for seabirds and marine mammals in New Zealand allows an absolute risk score to be assigned and contains a measure of uncertainty [48]. Tools are being developed under the Ocean Modelling Forum to assist data-poor fisheries with assessing fishery related impacts on marine mammals when Potential Biological Removal analyses are not possible [49]. The EASI-Fish framework approach estimates vulnerability of a variety of species to fisheries effects, and can consider multiple fisheries simultaneously, as well as examine potential effects of conservation measures on estimated vulnerability [50].

Methods for undertaking quantitative assessments when data are missing are also being developed, for example applying missing demographic parameters using a hierarchical framework rather than using data from conspecifics is improving population assessments [51,52]. Accessibility of tools to assess impacts is also improving, for example through the development of Shiny apps to assess impacts of wind farms or fisheries on seabirds [53,54].

The MSC has developed an appropriate and precautionary PSA for birds, mammals and reptiles to support the implementation of the MSC Fisheries Standard v3.0. This PSA will be subject to periodic revisions to ensure that it remains so, in line with adaptive management practices. The existence of the MSC Fisheries Standard Toolbox will allow tools to be added to facilitate the use of MSC standard and increase accessibility; for example, the Benthic Impacts Tool for habitats added in 2022 [41]. The next step for the MSC will be to evaluate the appropriateness of other tools and calibrate them with the MSC Standard v.3.0 to allow fisheries to better assess absolute impacts on birds, mammals and reptiles.

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CRediT authorship contribution statement

Caterina Fortuna: Investigation, Methodology, Writing – review & editing. **Bryan P Wallace:** Investigation, Methodology, Writing – review & editing. **Richard A Phillips:** Supervision, Validation, Writing – review & editing. **Keith Sainsbury:** Methodology, Writing – review & editing. **Polly Burns:** Conceptualization, Methodology, Writing – review & editing. **Kate Dewar:** Conceptualization, Methodology, Writing – review & editing. **Stephanie Diane Good:** Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. **Rohan J C Currey:** Conceptualization, Methodology, Validation, Writing – review & editing. **Edward F Melvin:** Investigation, Validation, Writing – review & editing. **Bruce Robson:** Investigation, Writing – review & editing. **Vinay Udyawer:** Investigation, Methodology, Writing – review & editing.

Data availability

No data was used for the research described in the article.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2024.106118.

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