Review of the MSC Productivity Susceptibility Analysis for Out-of-Scope Species

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Executive Summary

Birds, mammals, reptiles and amphibians are outside of the scope of the MSC program, yet they are often encountered by fisheries seeking certification. The impact of a fishery on these species is assessed in two components: Secondary species (PIs 2.2.x) and Endangered Threatened and Protected (ETP) species (PIs 2.3.x). When information to determine an impact is insufficient, the MSC requires the use of a Productivity and Susceptibility Analysis (PSA). However, the productivity and susceptibility attributes provided were not specifically designed for use with out of scope species. The MSC commissioned this review to determine whether current PSA attributes are appropriate to achieve a rigorous and precautionary assessment of the risk of fishing activities on out of scope species and, if not, provide recommendations for alternative approaches or attributes.

This approach used to achieve this objective was to:

1) Compare MSC certified fisheries scores for out of scope species using the default tree and the RBF PSA for up to two species per species group (groups: pelagic seabirds, diving seabirds, cetaceans, pinnipeds, sea turtles, sea snakes, salamanders, frogs).
2) Review logic in application of scoring attributes and thresholds and conformity of application of requirements in the current MSC assessment that has applied the PSA for out of scope species.
3) Undertake a literature review to determine whether current MSC productivity and susceptibility attributes are appropriate for the assessment of the species groups based on life history strategies of representative species and attributes applied in other PSA methods used globally.

A direct comparison of MSC certified fisheries scores with PSA scores for out of scope species was challenging as the PSA approach is different than that of the default tree. This is especially true for the ETP PI, where the default tree requires an assessment of whether the species is within limits set by management (if applicable), the likelihood that the fishery hinders recovery of the species and whether the fishery has indirect impacts of the species. Of these, only the likelihood that the fishery hinders recovery of the species corresponds to what is being evaluated in the PSA. In addition, not all assessment reports contained the level of detailed information needed to score the susceptibility attributes. So, this should also be borne in mind when considering results. In five of eight assessments reviewed, the PSA score was higher than the default tree score, so the PSA was not consistently precautionary.

[text redacted-certain sensitive fishery-specific information has been removed]

The literature review of life history characteristics examined the productivity attributes that were most appropriate to estimating population growth rate and practical to apply and susceptibility attributes that allowed overall catchability to be determined. For seabirds, mammals and reptiles, two attributes were established as being useful for all groups: average age a maturity (i.e. age at first reproduction) and fecundity. For seabirds average maximum age could also be useful. For mammals, a tweak on average maximum age to account for reproductive senescence could be useful. For sea snakes, average maximum size was considered more practical to evaluate than age. Amphibians life history characteristics were reviewed but given there was little evidence that they are caught in bycatch and none that it impacts on their populations, they were not considered further in this review. For all species

groups, the current susceptibility attributes were appropriate but more guidance on application would be useful.

For the review of application of other PSA approaches for out of scope species, a total of 14 different assessments were reviewed: three for seabirds, two for sea turtles, one for sea snakes, two for cetaceans and six multi-species assessments including one or more out of scope species groups, but also including fish. For the taxa-specific assessments, a number of attributes or thresholds differed from those used in the current PSA. Some of these were considered useful, either on their own or as a way of adapting or interpreting current attributes or thresholds (see Appendix 2).

In conclusion, the review of MSC PSA compared to default tree scores, despite caveats, indicates that the current PSA approach is not precautionary when applied to out of scope species. In addition, the review of the only current application of the PSA for out of scope species in an MSC assessment shows that it is challenging to apply the PSA for out of scope species, which leads to incorrect or inconsistent outcomes. The overall review of the appropriateness of attributes considering the life history characteristics of the different species groups also showed that many of the current attributes and thresholds are either inappropriate or redundant. To address this, it is recommended that attributes and thresholds are revised (see Table 11 for recommended attributes by species group). In addition, the following recommendations were made: 1) Consider and clearly specify the objectives for using the PSA, as linked to PIs in the default assessment tree; 2) Undertake new calibration precaution level in RBF scores for PI 2.2.1 and 2.3.1, using a range of out-of-scope species; 3) Specify that scoring of PSA attributes should be done at the smallest relevant unit (population); 4) Review elements of PIs where out of scope species are scored that are not currently captured in PSA and consider how they could be incorporated (if deemed relevant) in PSA attributes, thresholds or associated guidance.

Background

Birds, mammals, reptiles and amphibians cannot be certified to carry the Marine Stewardship Council (MSC) ecolabel and are therefore considered ‘out of scope’ species. However, these species may be encountered by fisheries seeking certification, and the impact of the fishery on the populations of these species must be considered. The impact of a fishery on these species is assessed in two components: Secondary species (Performance Indicator (PIs) 2.2.x) and Endangered Threatened and Protected (ETP) species (PIs 2.3.x) (MSC 2018a).

Conformity assessment bodies (CABs) conducting MSC fishery assessments are required to determine whether each species can be assessed using the default assessment tree or whether the Risk Based Framework (RBF) must be triggered. The criteria for secondary species to be allowed to use the default assessment tree is that there are biologically based limits available, derived either from analytical stock assessment or using empirical approaches. The criteria for ETP species to be allowed to use the default assessment tree is that the impact of the fishery in assessment on the ETP species can be analytically determined (MSC 2018a).

If the RBF is triggered, the out of scope species is assessed using a Productivity Susceptibility Analysis (PSA). The PSA is a semi-quantitative, relative risk method developed under the Ecological Risk Assessment for the Effects of Fishing (ERAEF) in Australian fisheries by Hobday et al (2007, 2011) and adapted for use by the MSC to ensure that its assessment process is accessible to data-deficient fisheries that are operating in a precautionary manner (MSC 2018b). Risk is defined by Hobday et al 2011 as the probability that a (specified) fishery management objective is not achieved, however in the MSC context it is not explained how the risk categories relate to the probability of the fishery failing to achieve the MSC objectives (Hordyk and Carruthers 2018).

The PSA is used to assess the relative risk that fishing activities cause an unacceptable amount of change to the population dynamics of the species in question (Hobday et al 2011). The PSA assumes that this risk is based on the inherent productivity of a species and the susceptibility of the species to fishing activities (Hobday et al 2007). Attributes that contribute or reflect productivity and susceptibility were thus selected to allow calculation of the relative risk.

The attributes selected and the threshold values for scoring the productivity attributes as low, medium and high were developed after considering the distribution of attribute values for a wide range of taxa within Australia (Hobday et al 2007). The MSC adopted these same attributes and thresholds. The MSC Guidance to FCP v2.1 (2018b) recognizes that "in testing this approach in subsequent discussion…and validating the attributes against the intrinsic rate of increase (r), we have improved our understanding to recognise that taxa-specific cut-offs and geographic (tropical vs temperate vs deep sea) maybe appropriate. This can be further improved by additional research, and MSC work is ongoing to progress this."

The MSC have commissioned this review with the objective of determining whether the current PSA attributes are appropriate to achieve a rigorous and precautionary assessment of the risk of fishing activities on out of scope species and if not, provide recommendations for alternative approaches or attributes.

Methods

Comparison of MSC default tree and PSA scores

The MSC databases 'MSC_P2_Species', 'P2 ETP Species Designations' and '20190624_All_ScoringIssues' were used to identify up to two out of scope species within each species group for review. The species groups were identified in the Terms of Reference for this review as: Pelagic seabirds, Diving seabirds, Cetaceans, Pinnipeds, Sea turtles, Sea snakes, Salamanders and Frogs. Selection of species for review within these groups was based on the following criteria:

- Recent assessment (FCR v2.0 ideal, but some CR v1.3 acceptable)
- Ensure diversity of species within species group (e.g. different sizes, life history strategies)
- Ensure diversity of fishing gears being assessed
- Risk (e.g. if there was a condition applied to the default tree score for the species)
- Enough information in the assessment to score susceptibility attributes

These criteria were used to select species for all species groups except for amphibians. Based on review of all available databases, no MSC certified fishery has recorded an interaction with an amphibian in its assessment. A literature review only revealed one paper reporting on amphibian bycatch – mudpuppies were caught in a Canadian recreational ice fishery (Lennox et al 2018). Although many amphibian species are in decline globally, bycatch in fisheries is not listed amongst the factors driving this (Collins & Storfer 2003; Sodhi et al 2008). The mudpuppy was selected as one species due to its lone bycatch report, and the other species selected were those known to be targeted, either as bait or the pet trade (Eastern tiger salamander), or directly for human consumption (Indian bullfrog, Goliath frog).

For all species selected an Excel database was compiled with information from the relevant fishery assessment including PI, gear, species and default tree score for the relevant scoring issue and scoring element within the assessment. For example, for ETP species, the scoring element (species) score for PI 2.3.1, scoring issue b was used. This is because in PI 2.3.1 scoring issue a is about whether a species is within limits, which is a different question than what is being assessed as a risk in the PSA. The PSA risk assessment is more closely aligned with PI 2.3.1 SI b, which looks at the likelihood that the fishery is hindering recovery of the ETP population.

A list of the current PSA attributes was added for each species in the Excel database. A risk score was then recorded for each attribute, along with a rationale. For productivity attributes, information was collected from the literature (see 2.3 Literature Review).

For susceptibility attributes, information was taken from the relevant fishery assessment. This latter point proved challenging, as most assessments reviewed did not have the level of detail needed to score all susceptibility attributes, particularly encounterability and selectivity. In some cases, assumptions could be made based on information provided but in others it was not possible to conduct a meaningful analysis (i.e. one where not all scores would default to high risk due to lack of information in the report, where there would likely be more information in reality).

The PSA combined risk scores and resulting MSC scores, calculated using the MSC RBF worksheet v2, were recorded (where possible, given not all susceptibility attributes were scored) so that they could be compared to the default tree score.

In addition, each attribute and threshold were reviewed to see if they were logical and precautionary for the species being assessed. This logic review included whether the attribute and thresholds were applicable for the species based on information from the literature (see 2.3 Literature Review). This was also recorded in the Excel file so the data could be analysed.

Review of scoring attributes in CAB application of MSC PSA

The MSC database 'RBF Data_FSR_2019' was used to identify MSC fishery assessments that used the PSA for out of scope species. The PSA methodology has only been applied to out of scope species in one fishery assessment to date, *[text redacted]*.

An Excel database was compiled with information from *[text redacted]* including: species, species group, Performance Indicator (PI), attribute, attribute score, rationale for attribute score and overall risk score and MSC score. The attribute scores and rationales assigned were reviewed and, where the review resulted in a change of score, these were recorded in the Excel file along with rationale. Any resulting changes to overall risk score and MSC score, calculated using the MSC RBF worksheet v2, were also noted.

Each attribute and threshold were reviewed to see if they were logical for the species being assessed. This logic review included whether the attribute and thresholds were applicable for the species, and – if applicable – if there were any issues with how they were implemented. This was also recorded in the Excel file so the data could be analysed.

Literature review

A literature review was undertaken to address the following two objectives:

1. Define life history strategies of representative species
2. Identify attributes applied in other PSA methods used globally.

Objective 1 required sources with demographic information for a multitude of species. The Ecological Risk Assessment for Effects of Fishing (ERAEEF) on which the MSC Risk-Based Framework is based approach relies on FishBase[1], and a similar database exists for out of scope species: SeaLifeBase[2]. The International Union for the Conservation of Nature (IUCN) RedList[3] is also a useful source of information on specific species/populations. In addition, some demographic information on species groups and impacts of fisheries on species can be found in through sites of non-governmental organisations (NGOs) or international agreements, e.g. State of the World's Sea Turtles (SWOT)[4]; BirdLife International Data Zone[5]; Agreement on Conservation of Albatross and Petrels (ACAP) species assessments[6]; International Whaling Commission (IWC)[7]; the Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS)[8]; Amphibian Survival Network (Amphibiaweb)[9]. Where information is not obtainable from these sources, then a search using the databases and tools described for objective 2 will be conducted for the specific species and the demographic characteristics related to the attribute in question.

The databases and search engines included for the literature search for objective 2 includes Web of Science (WoS), Google Scholar[10] and Google[11]. WoS and Google Scholar would return results primarily for scientific papers. Google was used as a Web browser in order to identify results from grey literature, including governments, RFMOs, international agreements or instruments (e.g. ACAP, ASCOBANS, IWC) and NGOs. In addition, where any reviews of risk-based approaches for any of the species groups have been undertaken (e.g. for seabirds, Small et al 2013), the tertiary sources within those documents will be identified and included in the literature review. This should also help identify approaches used that are from grey literature.

The list of search terms and sources used for each topic are identified in Table 1.

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[1] www.fishbase.org/
[2] https://www.sealifebase.ca/
[3] https://www.iucnredlist.org/
[4] https://www.seaturtlestatus.org/
[5] http://datazone.birdlife.org/species/search
[6] https://www.acap.aq/en/acap-species
[7] https://iwc.int/status
[8] https://www.ascobans.org/en/species
[9] https://amphibiaweb.org/
[10] https://scholar.google.com/
[11] https://www.google.co.uk/

Table 1 Search terms and sources used for literature review objectives

Objective	**Sources**	**Search terms**
1. Define life history strategies of representative species	SeaLifeBase IUCN RedList SWOT BirdLife International ACAP IWC ASCOBANS Amphibian Survival network (Amphibiaweb) Google Scholar Web of Science	Search by species/population for specific demographic parameters and/or attributes, e.g. "Wandering albatross" AND "fecundity"
2. Identify attributes applied in other PSA methods used globally.	Web of Science Google Scholar Google	"PSA" "Productivity Susceptibility Analysis" "Productivity" "Risk" AND "fisheries" "Impact assessment" "Risk assessment" AND species / species group name

Results and Discussion

Comparison of MSC default tree and PSA scores

It is difficult to directly compare the PSA scores with the default tree scores. The approach and requirements being assessed are slightly different – the PSA provides an estimate of relative risk of impact from a UoA, which is then converted into the MSC score. The PIs within the default tree are assessed against specific criteria and an absolute MSC score is assigned directly. For the Secondary species outcome PI (PI 2.2.1) the requirement evaluated is the likelihood that species is above its biologically based limit (or if below limit, measures/strategy in place to ensure fishery does not hinder recovery). It is more complicated in the Endangered, Threatened and Protected species PI (PI 2.3.1). There are three separate scoring issues in PI 2.3.1 – the first is scored if there are limits for protection and rebuilding of the ETP species and relate to whether the impacts from the fishery are likely to be within those limits. The second is about the likelihood that direct effects of the UoA do not hinder recovery of the species – this is the most similar aspect to what is being evaluated in the PSA. The third scoring issue is about whether the fishery has indirect (e.g. food web) impacts on the species. An overall score is assigned based on an assessment of the species against these three scoring issues. However, if the PSA is used, then a score for species is assigned for the whole PI, although the PSA does not include an assessment of whether the impacts are within limits or whether there are indirect impacts. Therefore, results of a direct comparison between the default tree and the PSA scores should be treated with caution. Generally speaking, however, it would be expected that the PSA-derived MSC scores would be lower than those for the default tree as the PSA was designed to be more precautionary.

A further difficulty with this analysis was that there was not enough information provided in all assessment reports to score susceptibility attributes, namely there was not enough detail on the area of fishery operation and gear configuration in all reports. In an actual PSA, stakeholders would be invited to provide information and expertise on scoring the susceptibility attributes. In the full assessments reviewed, even where there was some information on susceptibility, results should be interpreted with caution as they are based on assumptions and information provided, rather than interviews with wide group of expert stakeholders.

With these caveats in mind, Table 2 provides an overview of the PSA and default tree Performance Indicator 2.3.1 overall and scoring issue b score for eight species from five species groups where this was possible and results would be meaningful for this analysis (i.e. where there were too many attributes that would score the default high risk due to lack of information only, it was not considered meaningful). In five of eight assessments reviewed, the PSA score was higher than the default tree score (both PI and scoring issue), although in all but one of these the scoring range (‹60, 60-80, 80+) assigned was consistent with the default score. However, since the actual value PSA score is used for the PI, the higher value could make a difference to the aggregate Principle score. This indicates that the PSA may not be precautionary for out of scope species.

*Table 2 PSA vs default tree score (PI and scoring issue). Grey shading indicates where PSA score is higher than that given for the default tree. *note that the score provided is based on that for the particular scoring element (species).*

Species	**Species group**	**Assessment**	**PI**	**PSA score**	**Risk category**	**PSA MSC score**	**Scoring issue b score***	**Overall PI score***
White-chinned petrel (*Procellaria aequinoctialis*)	Pelagic seabird	*[text redacted]*	2.3.1	3.06	Medium (60-79)	65	60	75
Marbled murrelet (*Brachyramphus marmoratus*)	Diving seabird	*[text redacted]*	2.3.1	2.26	Low (>=80)	90	80	80
Common loon (*Gavia immer*)	Diving seabird	*[text redacted]*	2.3.1	2.82	Medium (60-79)	74	60	65
North Atlantic right whale (*Eubalaena glacialis*)	Cetacean	*[text redacted]*	2.3.1	3.14	Medium (60-79)	62	80	75
Harbour porpoise (*Phocoena phocoena*)	Cetacean	*[text redacted]*	2.3.1	2.94	Medium (60-79)	70	80	90
Leatherback turtle (*Dermochelys coriacea*)	Sea turtle	*[text redacted]*	2.3.1	2.81	Medium (60-79)	75	60	70
Short-nosed sea snake (*Aipysurus apraefrontalis*)	Sea snake	*[text redacted]*	2.3.1	2.49	Low (>=80)	84	60	75
Elegant sea snake (*Hydrophis elegans*)	Sea snake	*[text redacted]*	2.3.1	2.69	Medium (60-79)	78	60	75

Review of scoring attributes in CAB application of MSC PSA

[text redacted]

Review of appropriateness of attributes and thresholds

The rate of growth of a population can be determined, in its most basic way, using the Euler-Lotka equation (Lotka, 1907; Keyfitz, 1968). This equation specifies the relationships of age at maturity, age at last reproduction, probability of survival to age classes, and number of offspring produced for each age class, to the rate of growth of the population (r) (Weimerskirch 2002). Productivity attributes that directly relate to these relationships, including those used in the current PSA, are generally appropriate.

The life history characteristics described in the Euler-Lotka equation may also be linked through allometric relationships. For example, body mass (an indicator of size) has been shown to be a determinant of life history variations for selected birds and mammals (Gaillard et al 1989). However, Weimerskirch (2002) notes that although minimum age of at first breeding and life expectancy have an allometric relationship to body mass, that when the parameters are corrected for the effect of body mass, relationships between demographic traits are still very significant, e.g. the relationship between fecundity and life expectancy. Thus, size may not always be a necessary attribute to include as the other attributes provide explanatory power without it.

The susceptibility attributes used in the PSA are based on the approach from Walker 2005, as also applied in Hobday 2007, 2011. This approach considers that overall catch susceptibility is the product of availability, encounterability, selectivity and post-capture mortality (for non-retained species) (Walker 2005).

Seabirds (Pelagic seabirds & diving seabirds)

Croxall et al 2012 defines pelagic seabirds these as those that primarily use marine pelagic deep water and/or marine neritic pelagic continental shelf water, excluding species that may occasionally use these habitats. Coastal seabirds are those that primarily use coastal inshore water (‹8km from shoreline) either through the year or during non-breeding season. The species group 'diving seabirds' identified in this review could be better classified as coastal seabirds.

Both pelagic and coastal seabirds generally are characterised by high adult survival rates, low reproductive rates and delayed onset of maturity (Nisbet 1989, Croxall & Rothery 1991). These features, common to k-selected species, make seabirds particularly vulnerable to anthropogenic impacts that affect adult survival – including mortalities associated with fisheries bycatch (Anderson et al 2011). Croxall et al 2012 indicates that pelagic seabirds tend to have higher IUCN Redlist classifications than coastal seabirds – most likely due to demographic characteristics, small population sizes and restricted number and range of breeding sites.

It is important, therefore, when selecting productivity attributes and thresholds, that they reflect the distinctions between these two groups in terms of impacts on population growth rate .

When the current PSA is applied to selected species, in general the species with lower maximum growth rate (r_{max}) had higher risk scores (Appendix 1, Table A1.1). However, it is likely that there would be greater differentiation in overall productivity scores if only key attributes were selected and the thresholds were calibrated to the species group.

The current attributes considered most appropriate for seabirds based on the outputs of the literature review and analysis of application of the attributes using the current PSA method on example species, were average age at maturity, average maximum age and fecundity (Table 4). None of the current thresholds were appropriate for seabird species (Table 4).

In a review of risk-based approaches for seabirds Small et al 2013 considered susceptibility as measuring the degree overlap of fishing effort and seabird distribution, but also taking into account selectivity (e.g. such as longline hook size affects the size range of species caught) and encounterability (e.g. surface feeders like albatrosses and petrels are captured by longlines whereas diving species like shags, penguins, shearwaters, alcids and ducks are more likely to encounter to gillnets). These susceptibility considerations are in line with those currently used in the MSC requirements, but the thresholds for most seabird risk assessments are more specific.

In addition, Small et al 2013 reviews how seabird distribution should be considered in a PSA, depending on the level of information available, from expert opinion through to modelling of distribution based on analysis of habitat preference (including use of tracking data). The middle levels of data would include using range maps and assuming homogeneous distribution throughout the range, using range maps to represent non-breeding distribution and a foraging radius to represent breeding distribution, or using a combination of range map, foraging radius and tracking data, as available. Small et al 2013 provide general advice on the approach, given each of the types of information used has its own drawbacks. Using tracking data to estimate foraging radius based on a mean maximum of all trips, where this information is available, is recommended. Also, estimation of distribution at least quarterly is recommended given the highly seasonal nature of seabird (and fishing effort) distribution. For the SeafoodWatch standard, Monterey Bay Aquarium are considering adding an attribute on seasonality to account for seasonal overlap (Monterey Bay Aquarium 2019). This method could be compared to that of having the availability attribute score account for the period with highest overlap.

All of the current susceptibility attributes were considered appropriate for seabirds (Table 5). Only the post-capture mortality thresholds, however, were considered appropriate (Table 5).

Table 3 Evaluation of Current Productivity Attributes & Thresholds for seabirds

Attribute	Appropriate for species group	Rationale	Threshold	Appropriate for species group	Rationale
Average age at maturity	Yes	In seabirds generally expressed as 'age at first breeding (or reproduction)'. When compared to other birds, seabirds breed at older age (Weimerskirch 2002). However, this is not known for many seabird species or may be based only on a few recaptures rather than average across a population, so may lead to default high risk scores when precautionary approach is applied.	Low p (high risk): ›15 years, Medium: 5-15 years, High: ‹5 years	No	Age at first reproduction for species with lowest value r_{max} in NZ risk assessment (*Diomedea* spp) is approximately 10-12 years (Richard et al 2017). This would only be medium productivity using current thresholds when it should be high.
Average maximum age	Yes	Average longevity used as a proxy for adult survival (which can be difficult to calculate) (Weimerskirch 2002). However, this is not known for many seabird species or may be based only on a few recaptures rather than average across a population, so may lead to default high risk scores when precautionary approach is applied.	Low p (high risk): ›25 years, Medium: 10-25, High: ‹10 years	No	Data not available for all species. Diomedea have life expectancy of 11.6-33.8 years and Procellariidae between 6.9-25.5 years in Weimerskirch 2002. Although they have different growth rates (Diomedia have slower), they would both be considered high risk with this threshold.

Attribute	Appropriate for species group	Rationale	Threshold	Appropriate for species group	Rationale
Fecundity	Yes	Seabirds tend to have low fecundity (taking into account clutch size, breeding frequency and breeding success) but there is variability within this parameter, e.g. with the great albatrosses laying one egg every two years compared to species of gull which lay three eggs every year and may be able to reproduce a second time within the year if their first clutch is lost (Weimerskrich 2002).	Low p (high risk): ‹100 eggs per year; Medium: 100-20,000 eggs per years; High ›20,000 eggs per year	No	Only considers number of eggs, all seabirds lay less than 100, so all would be high risk. Also should consider other elements of fecundity such as frequency of breeding.
Average maximum size	No	Body mass (size) is significant but not fundamental determinant of variation in demographic rates of seabirds (Weimerskirch 2002). However, age at first breeding and maximum age have significant relationship to population growth rate when parameters are corrected for body mass (Weimerskirch 2002), so size-related parameters may be redundant here. Moreover, it is not clear what aspect of size should be considered for seabirds, e.g. wingspan, body length, mass.	Low p (high risk): ›300cm, Medium: 100-300 cm; High: ‹ 100 cm	No	Not clear how this should be measured for seabirds – body length or wingspan. If using longer of the two measurements to be precautionary, largest seabird would be wandering albatross (wingspan ›300cm) but most other species would fit in low/medium categories.

Attribute	Appropriate for species group	Rationale	Threshold	Appropriate for species group	Rationale
Average size at maturity	No	As for average maximum size.	Low p (high risk): ›200 cm, Medium: 40-200 cm, High ‹40 cm	No	Not clear how this should be measured for seabirds – body length or wingspan. Thresholds may be more appropriate than for average maximum age as set lower, although, as seabirds tend to breed later, size at maturity is close to maximum size so thresholds should be aligned.
Reproductive strategy	No	All seabirds are egg-layers. Hobday et al (2007, 2011) group birds with live bearers. Therefore, all species within this group would be high risk. If the frequency of breeding and clutch size are taken into account in fecundity, this attribute becomes redundant.	Low p (high risk): Live bearer; Medium: Demersal egg layer; High: Broadcast spawners	No	Seabirds do not fit into any of the categories provided – they are not live bearers, demersal egg layers or broadcast spawners. Hobday et al 2007, 2011 include bird species with live bearers. All would be high risk.

Attribute	Appropriate for species group	Rationale	Threshold	Appropriate for species group	Rationale
Trophic level	No	TL often increases with longevity and size but these attributes are already covered (Duffy & Griffiths 2017, Hordyk and Carruthers 2018). Seabirds cover a range of trophic levels but data on a specific trophic level is not always provided (more common to use rations of stable isotopes of nitrogen and carbon to identify trophic levels) (Shealer 2002). Trophic level can be different between populations within the same species, or even within the same population over different seasons, based on where they forage and prevailing environmental conditions (Gagne et al 2018).	Low p (high risk): ›3.25, Medium: 2.75-3.25, High ‹2.75	No	This information was not available for most species. Where it was (white-chinned petrel), it was 3.6 so would be high. The CAB assessment did not specify a trophic level but listed all seabirds as high. They would in fact have greater diversity than this, as they feed at a range of trophic levels (Shealer 2002).

Table 4 Evaluation of Current Susceptibility Attributes & Thresholds for seabirds

Attribute	**Appropriate for species group**	**Rationale**	**Threshold**	**Appropriate for species group**	**Rationale**
Areal overlap (Availability)	Yes	Overlap with fisheries is a main element of catchability (Walker 2005)	Low risk: <10% overlap, Medium: 10-30% overlap; High: >30% overlap	No	Seabirds are generally wide-ranging except e.g. during breeding season, so overlap generally scored as low. Need to identify distribution period and/or population/ age / sex where there is most risk, describe approaches to use based on Small et al 2013 guidance, and score on that to be precautionary. Also could look at % overlaps and risk scores overall.
Encounterability (water column position and habitat)	Yes	Encounterability is a main element of catchability (Walker 2005). May need to be defined for species that interact with gear at/above surface (Hobday et al 2007).	Low risk: Low overlap with fishing gear (low encounterability) Medium: Medium overlap with fishing gear. High: High overlap with fishing gear (high encounterability).	No	Can be described based on species within water column relative to the gear or overlap with habitat. But seabird interactions occur at/above the surface for active gear interactions and usually during specific periods (setting/hauling). More specificity needed on thresholds.

Attribute	Appropriate for species group	Rationale	Threshold	Appropriate for species group	Rationale
Selectivity	Yes	Selectivity is a main element of catchability (Walker 2005). This is very gear and species specific.	a: Low risk: individuals < size at maturity are rarely caught. Medium: individuals < size at maturity are regularly caught. High: individuals < size at maturity are frequently caught. b: Low risk: individuals < size at maturity can escape or avoid gear. Medium: Individuals < half the size at maturity can escape or avoid gear. High: Individuals < half the size at maturity are retained by the gear.	No	As long-lived species, adult survival has more impact on population growth than juvenile. So basing the thresholds on size / age here not useful in terms of risk categorisation. Also selectivity varies depending on gear used and species attributes. More appropriate to develop gear/species matrix.
Post-capture mortality	Yes	PCM is important to consider for species not retained to estimate risk of overall catchability (Walker 2005)	Low risk: Evidence of majority post-capture release and survival; Medium: Evidence of some released post-capture and survival; High: Retained species or majority dead when released. Default for retained species	Yes	Requires evidence to support risk category. There is some information on PCM for seabirds in some fisheries, but default should be to score as high risk where there is no information.

Marine mammals (cetaceans and pinnipeds)

Like seabirds, marine mammals tend to have life history strategies that comprise high adult survival, late maturity and low fecundity (Lewison et al 2004). In general, cetaceans have a lower maximum growth rate than pinnipeds, and they therefore are more susceptible to anthropogenic mortality (Breen 2017, Wade 1998).

Cetaceans can be broadly categorised into two main groups: baleen whales (mysticetes) and toothed whales (odontocetes) (Reeves et al 2002). Baleen whales include some of the largest mammals on earth but feed on zooplankton, crustaceans and small fish. Toothed whales, which also include dolphins and porpoises, vary in size and tend to feed on fish and squid, but some feed on mammals and birds. Across and within these groups (and sometimes even within species) there are life history parameters that make some more inherently vulnerable than others, and this is not always related to size. For example, the Maui's dolphin is a small cetacean (1.2-1.7m) with a short lifespan compared to other cetaceans, but who have a relatively late age at maturity and low fecundity (Currey et al 2011). This makes them particularly vulnerable to anthropogenic mortality despite their small size.

Pinnipeds can be broadly split into three groups eared seals (Otariidae), walrus (Odobenidae) and true seals (Phocide) (Reeves et al 2002). There are a variety of life history strategies within and these groups. For example, reproductive strategies for elephant seals are characterised as extreme polygamy and in harbour seals and monk seals are monogamous (Reeves et al 2002). Despite the differences in breeding social structure, all pinnipeds give birth once a year to a single pup (Reeves et al 2002). Polygamous pinnipeds often show sexual dimorphism, so when considering size at maturity and maximum size, it is important to decide which sex should be considered. A consistent maximum population growth rate is used to calculate Potential Biological Removal (PBR) for all pinnipeds in the US Marine Mammal Risk Assessment (Wade 1998). In Canada, for walrus the maximum growth rate used to calculate PBR is slightly lower than for pinniped species in other assessments (Hammill 2016). In the New Zealand risk assessment for marine mammals, there is little difference in the calculated maximum growth rates between the three pinniped species included (New Zealand fur seal, New Zealand sea lion, Southern elephant seal), and these values are similar to those used in the US (Abraham et al 2017). So, it may be appropriate that similar risk values come out of the PSA for these species, particularly if they are grouped in the same category as other marine mammals.

When the current PSA is applied to selected species across the marine mammal group, the productivity scores did not correspond to the maximum growth rates as would be expected if the attributes and thresholds were appropriate (Appendix 1, Table A1.2). For example, it would be expected that all of the pinnipeds had lower productivity scores than cetaceans given their higher maximum growth rate, but this was not the case. This shows that the current application of the PSA is not appropriate for marine mammals as a group.

There were groups of marine mammals not considered here, but which may be subject to bycatch include sea otters and sirenians (e.g. dugongs and manatees). Calibration of attributes should consider life history strategies of these species groups as well.

Two of the seven current productivity attributes were considered appropriate for marine mammals (age at first reproduction and fecundity), with a further one potentially being useful if tweaked (average maximum age). None of the thresholds were considered appropriate. If cetaceans and pinnipeds are to be considered within the same grouping, it would be expected that most cetaceans score higher risk for productivity than pinnipeds. The key factor to ensure is represented is fecundity, particularly the breeding frequency.

As with other species, the likelihood of a marine mammal being caught and killed combines factors including areal overlap, gear, species size and behaviour. All of the current PSA susceptibility attributes are therefore appropriate but only the PCM threshold is appropriate. All the others would need to be calibrated across the species groups and potential gear interactions.

Table 5 Evaluation of Current Productivity Attributes & Thresholds for marine mammals

Attribute	Appropriate for species group	Rationale	Threshold	Appropriate for species group	Rationale
Average age at maturity	Yes	Referred to as 'age at first reproduction'. Age at first reproduction has relationship with population growth rate for mammals (Gaillard et al 1989)	Low p (high risk): >15 years, Medium: 5-15 years, High: <5 years	No	Cetaceans: AFR ranges from 5-14 years (Taylor et al 2007). All would be Low to Medium Risk. Should allow some to be high risk. Pinnipeds: Differs for males and females as males tend to be older before they can hold a territory. Not clear which value should be used. If use males as more precautionary then most pinnipeds would be low to medium risk.
Average maximum age	Yes (with tweaks)	Could be proxy for adult survival. Some cetacean species have reproductive senescence. So average oldest age of reproducing female may be more appropriate attribute (Taylor et al 2007)	Low p (high risk): >25 years, Medium: 10-25, High: <10 years	No	Cetaceans: Oldest age of reproducing females can range from 20 to 60+ (Taylor 2007) so most species would end up in high risk category. Pinnipeds: Ranges e.g. 15-20 for South American Sea Lion (PCR) to 35-40 for Grey seal (Reeves et al 2002). These would all be Medium or High risk.

Attribute	Appropriate for species group	Rationale	Threshold	Appropriate for species group	Rationale
Fecundity	Yes	Fecundity is an important element in consideration population growth rate for mammals (Gaillard et al 1989). Important factor for differentiating between cetacean species, e.g. Maui's dolphins (Currey et al 2011)	Low p (high risk): ‹100 eggs per year; Medium: 100-20,000 eggs per years; High ›20,000 eggs per year	No	All marine mammals have less than 100 offspring in a year, so all would be high risk. Also should consider other elements of fecundity such as frequency of breeding.
Average maximum size	No	Size is not best measure of vulnerability – e.g. some small cetaceans are more inherently vulnerable than large For pinnipeds in NZ risk assessment (Abraham et al 2017), not much difference in growth rate in different sized pinnipeds.	Low p (high risk): ›300cm, Medium: 100-300 cm; High: ‹ 100 cm	No	Smallest cetaceans will be in medium risk category. Largest will always be high risk. Pinnipeds vary by sex. All are ›1m (Reeves et al 2002), so will be medium or high risk.
Average size at maturity	No	Size is not best measure of vulnerability – e.g. some small cetaceans are more inherently vulnerable than large	Low p (high risk): ›200 cm, Medium: 40-200 cm, High ‹40 cm	No	Smallest cetaceans will be in medium risk category. Largest will always be high risk. Pinnipeds vary by sex. All › 1m (Reeves et al 2002) so would be medium or high risk.
Reproductive strategy	No	If the frequency of breeding and clutch size are taken into account in fecundity, this attribute becomes redundant.	Low p (high risk): Live bearer; Medium: Demersal egg layer; High: Broadcast spawners	No	All marine mammals are live bearers so all would be high risk.

Attribute	Appropriate for species group	Rationale	Threshold	Appropriate for species group	Rationale
Trophic level	No	TL often increases with longevity and size but these attributes are already covered (Duffy & Griffiths 2017, Hordyk and Carruthers 2018).	Low p (high risk): ›3.25, Medium: 2.75-3.25, High ‹2.75	No	Trophic levels ranged from 3.2–3.4 in baleen whales, 3.8–4.4 in most pinnipeds and odontocete whales, to 4.5–4.6 in killer whales (Pauly et al 1998). All would be considered high risk.

Table 6 Evaluation of Current Susceptibility Attributes & Thresholds for marine mammals

Attribute	Appropriate for species group	Rationale	Threshold	Appropriate for species group	Rationale
Areal overlap (Availability)	Yes	Overlap with fisheries is a main element of catchability (Walker 2005)	Low risk: ‹10% overlap, Medium: 10-30% overlap; High: ›30% overlap	No	Cetaceans are generally wide-ranging except e.g. during breeding season, so overlap generally scored as low. May need to identify distribution period and/or population/ age / sex where there is most risk and score on that to be precautionary. Also could look at % overlaps and risk scores overall. Pinnipeds are more localised in distribution so may be easier to score.

Attribute	Appropriate for species group	Rationale	Threshold	Appropriate for species group	Rationale
Encounterability (water column position and habitat)	Yes	Encounterability is a main element of catchability (Walker 2005). May need to be defined for species that interact with gear at/above surface (Hobday et al 2007).	Low risk: Low overlap with fishing gear (low encounterability) Medium: Medium overlap with fishing gear. High: High overlap with fishing gear (high encounterability).	No	Can be described based on species within water column relative to the gear or overlap with habitat. But marine mammal interactions occur at/above the surface for active gear interactions and usually during specific periods (setting/hauling). More specificity needed on thresholds.
Selectivity	Yes	Selectivity is a main element of catchability (Walker 2005). This is very gear and species specific.	a: Low risk: individuals < size at maturity are rarely caught. Medium: individuals < size at maturity are regularly caught. High: individuals < size at maturity are frequently caught. b: Low risk: individuals < size at maturity can escape or avoid gear. Medium: Individuals < half the size at maturity can escape or avoid gear. High: Individuals < half the size at maturity are retained by the gear.	No	As long-lived species, adult survival has more impact on population growth than juvenile. So basing the thresholds on size / age here not useful in terms of risk categorisation. Also selectivity varies depending on gear used and species attributes. More appropriate to develop gear/species matrix.

Attribute	Appropriate for species group	Rationale	Threshold	Appropriate for species group	Rationale
Post-capture mortality	Yes	PCM is important to consider for species not retained to estimate risk of overall catchability (Walker 2005)	Low risk: Evidence of majority post-capture release and survival; Medium: Evidence of some released post-capture and survival; High: Retained species or majority dead when released. Default for retained species	Yes	Requires evidence to support risk category. There is some information on PCM for bycatch mortality in some fisheries, but default should be to score as high risk where there is no information.

Reptiles (sea turtles and sea snakes)

There are seven species of marine turtles, and within these there are 58 individual regional management units (RMUs) – or populations – based on nesting locations and distribution data (Wallace et al 2011). Marine turtles vary in population size and trends, as well as reproduction and morphology across these RMUs (Wallace et al 2011).

Sea turtles, like seabirds and marine mammals are long-lived, late-maturing species, which makes them particularly susceptible to impacts like fisheries mortality that affect the adult life stages (Wallace et al 2013). Unlike seabirds and marine mammals, however, ontogenetic stages for marine turtles change radically from hatchling to adult in terms of relative contribution to population growth (Curtis & Moore 2013). The long time to maturity for sea turtles means that an individual juvenile turtle is likely to die before it reaches adulthood and contributes to population growth, however there is higher reproductive value for sub-adult turtles compared with hatchlings (Heppell 2005). However, there is generally a lack of age-specific information for the individual populations (Heppell 2005).

Population productivity is also highly dependent on local conditions that influence a number of factors relating to fecundity including: nest success (% nests producing hatchlings), emergence success (% eggs per nest emerging as hatchlings), mean number of eggs per female, the number of clutches per female per season and the remigration interval (i.e. the period between successive breeding seasons) (Nel et al 2013).

The current productivity attributes reviewed that were considered appropriate for sea turtles include age at maturity and fecundity (Table 8). None of the productivity thresholds were considered appropriate for this species (Table 8).

As with other out of scope species, the susceptibility to capture is based on a range of factors including overlap with fisheries, gears used, size of species, behaviour and diet. All current susceptibility attributes are therefore appropriate, but only the PCM threshold is appropriate (Table 9).

Sea snakes are venomous elapid snakes that inhabit the marine environment for most of their lives, predominantly in the tropical Pacific and Indian Oceans (Damotharan et al 2010). There are about 80 species of sea snakes, although identification to species can be difficult, and they inhabit shallow waters along coasts, around islands and coral reefs, river mouths and rivers (Rasmussen et al 2011). Although some species have wide distributions, others are highly localised, making them more vulnerable to impact (Rasmussen et al 2011). Sea snakes feed mainly on fish and eels (Rasmussen et al 2011). In tropical Australia and south-east Asia, sea snakes may be caught in trawls (Milton 2001). Bycatch mortality is one of the two most significant anthropogenic impacts on sea snake populations (Courtney et al 2010).

Most sea snakes are viviparous (one genus is oviparous) and tend to reproduce annually, with clutch size increasing with the size of the female (Rasmussen et al 2011). Lemen & Voris (1981) found than in 14 species of sea snakes collected around Malaysia, that average clutch size ranged from 2.9-17.8 young but most species had between 3 and 7 young. Fry et al (2001) found that in Australian waters clutch size ranged from 1-20 young.

Sea snakes share traits with other out-of-scope species reviewed here as they are live-bearing, have small clutches, are long-lived and have low reproductive output. Despite this, Rasmussen et al 2011 indicate that for most species there is a lack of information on breeding cycles, growth rates, population density, sexual maturity and taxonomy.

The current productivity attributes reviewed that were considered appropriate for sea snakes include age at maturity, average maximum size and fecundity (Table 8). None of the productivity thresholds were considered appropriate for this species (Table 8).

As with other out of scope species, the susceptibility to capture is based on a range of factors including overlap with fisheries, gears used and size of species. Some sea snake species are sexually dimorphic, with females being larger, which meant they were more susceptible to capture in Australian trawl fisheries (Fry et al 2001). All current PSA attributes are considered appropriate, but only the PCM threshold is appropriate (Table 9). Selectivity could also include some consideration of sex-specific mortality.

Given the differences in biology and available demographic information between sea turtles and sea snakes, separate PSA attributes and thresholds may be useful.

Table 7 Evaluation of Current Productivity Attributes & Thresholds for marine reptiles (turtles and snakes)

Attribute	Appropriate for species group	Rationale	Threshold	Appropriate for species group	Rationale
Average age at maturity	Yes	Referred to as 'age at sexual maturity'. Turtles & snakes: Has relationship with population growth rate (Heppell 2005). For turtles: some turtle species have very late maturation (+40 years) (Curtis & Moore 2013). However, very few data for this across species so may default to high risk.	Low p (high risk): >15 years, Medium: 5-15 years, High: <5 years	No	Turtles: Estimates are highly variable and uncertain and based on species rather than populations in many cases. For example, leatherhead turtle (largest turtle) estimates are 9-15 years in one study but 26-32 in another (IUCN RL) Snakes: For two species evaluated have low to medium risk (age range 2-5) even though one is largest sea snake in Australia. Need to compare across wider group to calibrate.
Average maximum age	No	Turtles & snakes: Could be proxy for adult survival. However, very few data for this across populations.	Low p (high risk): >25 years, Medium: 10-25, High: <10 years	No	Turtles: No reliable data found for average maximum age. Some estimates are available through skeletochronology (Heppell 2005). Estimates for largest turtle are about 43 and for smallest in rate of 18-20 (Eckert et al 2012, Reichart 1993). So would be med to high risk. Snakes: For two species evaluated, would be medium risk (10 years) even though one is largest sea snake in Australia. Need to compare across wider group to calibrate.

Attribute	Appropriate for species group	Rationale	Threshold	Appropriate for species group	Rationale
Fecundity	Yes	Fecundity is an important element in consideration population growth rate. For sea turtles the number of nests per year, number of eggs and hatchings per nest and female remigration (frequency of breeding) important to capture (Casale & Heppell 2016).	Low p (high risk): <100 eggs per year; Medium: 100-20,000 eggs per years; High >20,000 eggs per year	No	Turtles: All sea turtles would lay in regions of 10s to 100s of eggs per year, so all would be high risk. Also does not provide info on how to incorporate multiple nests and remigration in estimate. Snakes: Variable. Fry et al 2001 found clutch size was between 1-20 young. All would be high risk.
Average maximum size	No (Turtles) Yes (Snakes)	Could be proxy for maximum age but little information available for turtles. More info provided on snakes.	Low p (high risk): >300cm, Medium: 100-300 cm; High: < 100 cm	No	Turtles: Largest turtle (leatherback) would only be in medium risk category (1.9m estimated based on one population, Eckert 2012) Snakes: For two species evaluated, one is 60 cm and one is 210 cm, so low and med risk even though one is largest sea snake in Australia.
Average size at maturity	No	Could be proxy for age at maturity, but little information available for either turtles or snakes	Low p (high risk): >200 cm, Medium: 40-200 cm, High <40 cm	No	Turtles: Largest turtle (leatherback) would only be in medium risk category (1.4m estimated based on one population, Eckert 2012) Snakes: Unknown for 1 of 2 species evaluated. For other size a maturity at 100cm (IUCN RedList), medium risk, despite being largest sea snake in Australia.

Attribute	Appropriate for species group	Rationale	Threshold	Appropriate for species group	Rationale
Reproductive strategy	No	If the frequency of breeding and nest size are considered in fecundity, this attribute becomes redundant for both turtles and snakes.	Low p (high risk): Live bearer; Medium: Demersal egg layer; High: Broadcast spawners	No	Sea turtles do not fit into any of these categories. Sea snakes are mostly viviparous so would all be scored high risk.
Trophic level	No	TL often increases with longevity and size but these attributes are already covered (Duffy & Griffiths 2017, Hordyk and Carruthers 2018). Turtles: TL likely to vary based on location, size (life history stage) and species (Godley et al 1998). Not all populations (or even species) have estimates based on TL Snakes: No info found on specific TL for this species (or other sea snakes). Davenport 2011 also indicates that there are correlations between body size of snake the size of prey, so larger sea snakes would generally consume larger and more varied prey.	Low p (high risk): ›3.25, Medium: 2.75-3.25, High ‹2.75	No	Turtles: Comparison of loggerhead, leatherhead and green turtles by Godley et al 1998 showed that loggerhead occupy higher trophic level than leatherhead, which occupy higher TL than green. However, most trophic indication reported based on stable isotope analysis rather than specific TL Snakes: No information found

Table 8 Evaluation of Current Susceptibility Attributes & Thresholds for marine reptiles (turtles and snakes)

Attribute	**Appropriate for species group**	**Rationale**	**Threshold**	**Appropriate for species group**	**Rationale**
Areal overlap (Availability)	Yes	Overlap with fisheries is a main element of catchability (Walker 2005)	Low risk: <10% overlap, Medium: 10-30% overlap; High: >30% overlap	No	Sea turtles: generally wide-ranging except e.g. during breeding season, so overlap generally scored as low Sea snakes: Some species are widespread throughout tropical Pacific and Indian Oceans, while others are localised. May be migration from reefs to deeper waters at different times that would make them more susceptible. Both: May need to identify distribution period and/or population/ age / sex where there is most risk and score on that to be precautionary. Also could look at % overlaps and risk scores overall.

Attribute	Appropriate for species group	Rationale	Threshold	Appropriate for species group	Rationale
Encounterability (water column position and habitat)	Yes	Encounterability is a main element of catchability (Walker 2005). May need to be defined for species that interact with gear at/above surface (Hobday et al 2007).	Low risk: Low overlap with fishing gear (low encounterability) Medium: Medium overlap with fishing gear. High: High overlap with fishing gear (high encounterability).	No	Can be described based on species within water column relative to the gear or overlap with habitat. But sea turtle interactions occur at/above the surface for active gear interactions and usually during specific periods (setting/hauling). More specificity needed on thresholds.

Attribute	Appropriate for species group	Rationale	Threshold	Appropriate for species group	Rationale
Selectivity	Yes	Selectivity is a main element of catchability (Walker 2005). This is very gear and species specific.	a: Low risk: individuals < size at maturity are rarely caught. Medium: individuals < size at maturity are regularly caught. High: individuals < size at maturity are frequently caught. b: Low risk: individuals < size at maturity can escape or avoid gear. Medium: Individuals < half the size at maturity can escape or avoid gear. High: Individuals < half the size at maturity are retained by the gear.	No	As long-lived species, adult survival has more impact on population growth than juvenile. So basing the thresholds on size / age here not useful in terms of risk categorisation. Also selectivity varies depending on gear used and species attributes. More appropriate to develop gear/species matrix. Juvenile sea snakes of most species are not caught in Australia prawn trawls, suggesting there is little impact on this age class (Fry et al 2001). However, there is a larger proportion of females caught for sea snake species that are sexually dimorphic (females are larger) (Fry et al 2001). This could be considered as part of the selectivity thresholds.
Post-capture mortality	Yes	PCM is important to consider for species not retained to estimate risk of overall catchability (Walker 2005)	Low risk: Evidence of majority post-capture release and survival; Medium: Evidence of some released post-capture and survival; High: Retained species or majority dead when released. Default for retained species	Yes	Requires evidence to support risk category. There is some information on PCM for sea turtles and sea snakes in some fisheries, but default should be to score as high risk where there is no information.

Amphibians (frogs/toads and salamanders)

Amphibians are included by the MSC as the out of scope species but are very different biologically from the other species groups in this category. There is very little information on amphibian life history, particularly for Asian and African frogs selected for this review. Few studies have examined how life history traits correlate with recovery potential after population crashes (Sodhi et al 2008). In general, larger body sizes were thought to link to slower population growth rates, making this a key factor to consider (Sodhi et al 2008). However, bycatch in fisheries is not considered a main factor driving global declines in amphibians (Collins & Storfer 2003; Sodhi et al 2008).

The productivity attributes of the current PSA were reviewed for two salamander and two frog species to evaluate their appropriateness – the average maximum size and fecundity were both considered appropriate (Table 10). In the case of the Goliath frog, it had a higher risk score than might otherwise be warranted as there was very little life history information available on this species, so many values had to be scored as high risk as a default (Appendix 1, Table A1.4). This highlights the level of precaution inherent in the PSA methodology but also the problem of using attributes where very little data is available across a species group.

None of the thresholds were considered appropriate. As there were no MSC fisheries identified where susceptibility could be reviewed, this was not evaluated.

Table 9 Evaluation of current Productivity Attributes & Thresholds for amphibians (salamanders and frogs)

Attribute	Appropriate for species group	Rationale	Threshold	Appropriate for species group	Rationale
Average age at maturity	No	Age at reproduction and longevity poorly understood for many amphibians. Some information was found for the two salamander species but not for both frogs.	Low p (high risk): >15 years, Medium: 5-15 years, High: <5 years	No	For mudpuppy was 5-8 years (Amphibiaweb) – high risk. For others was 10-24 months (low risk). For one there was no information so defaulted to high risk score.
Average maximum age	No	Age at reproduction and longevity poorly understood for many amphibians. Some information was found for the two salamander species but not for both frogs.	Low p (high risk): >25 years, Medium: 10-25, High: <10 years	No	The two salamander species were 25+ years (Amphibiaweb) – high risk. One frog was estimated 7 years (low risk) and no information for the other so defaulted to high risk.
Fecundity	Yes	Amphibians have diverse reproductive cycles, and as a result various reproductive outputs (Hoque & Saidapur 1994). Frequency of breeding is variable, largely based on environmental and food conditions.	Low p (high risk): <100 eggs per year; Medium: 100-20,000 eggs per years; High >20,000 eggs per year	No	Salamanders: mudpuppy was 36-85 eggs depending on region (Amphibiaweb); ET salamander der was between 421-7631 eggs. Frogs: Indian bullfrog only known based on one captive study (4000 eggs) (Hoque & Saidapur 1994) Goliath frog "several hundred eggs" (Amphibiaweb) All would be in low to medium risk category

Attribute	Appropriate for species group	Rationale	Threshold	Appropriate for species group	Rationale
Average maximum size	Yes	Information was available for all the species considered. May be a proxy for adult survival.	Low p (high risk): >300cm, Medium: 100-300 cm; High: < 100 cm	No	Salamander: largest is 1.8m but most are smaller (mudpuppy is approx. 33cm, Amphibiaweb). Most would be low risk. Frog: largest frog species is 32cm but would still be low risk
Average size at maturity	No	If large that species would have less chance to breed before capture (assuming selectivity higher for larger animals). However, information is limited on this.	Low p (high risk): >200 cm, Medium: 40-200 cm, High <40 cm	No	Salamander: mudpuppy was 20cm (ET salamander smaller), would be low risk Frogs - for one used estimate based on maximum size as no info available. Maximum size was still less than threshold for low risk
Reproductive strategy	No	Categories not appropriate, same information captured better in fecundity.	Low p (high risk): Live bearer; Medium: Demersal egg layer; High: Broadcast spawners	No	None of the categories captures amphibians. All lay eggs but are not 'demersal'.
Trophic level	No	TL often increases with longevity and size but these attributes are already covered (Duffy & Griffiths 2017, Hordyk and Carruthers 2018). No trophic level was specified for any of the selected species.	Low p (high risk): >3.25, Medium: 2.75-3.25, High <2.75	No	Specific TLs not identified. Some indication of what they fed on was available – are generally low to medium TL based on prey.

Review of alternative attributes

A total of 14 different assessments using Productivity Susceptibility Analysis or a similar approach were reviewed: three for seabirds, two for sea turtles, one for sea snakes, two for cetaceans and six multi-species assessments including one or more out of scope species groups, but also including fish. Most of these were undertaken as a risk assessment of fishing within a Regional Fisheries Management Organisation (RFMO). In addition, three national assessments are included (Australia, Mexico and Uruguay) and three regional assessments (NE Atlantic, Irish Sea and SW Indian Ocean). A range of gear types are included comprising longline, purse seine, trawl, gillnets, pots and traps, divers.

Appendix 2 contains a table with all attributes reviewed, their thresholds and whether they are recommended as appropriate for inclusion in the MSC PSA.

Seabird-specific attributes

Three types of productivity attributes are included for seabirds: a Fecundity Factors Index (based on life history strategy and age at first breeding), Life history strategy and Demographic Invariant Method (using maximum growth rate, r_{max}). When deciding to select life history strategy as their only productivity attribute, Tuck et al (2011) evaluated other parameters but decided that life history strategy adequately captured the key differences between population growth rates of relevant species (Small et al 2013). The method using maximum growth rate was used in the Uruguayan risk assessment, but this approach is more quantitative and requires reliable data on adult survival and age at first breeding to determine (Small et al 2013). Observed values of population growth should not be substituted for r_{max} as they would already account for additional mortalities, e.g. though fisheries bycatch, and the productivity should be based on intrinsic parameters (Sharp 2017; Small et al 2013). Waugh et al (2012) in the risk assessment for WCPFC compared using r_{max} with the Fecundity Factors Index, which included life history strategy and age at first breeding and found them correlated. Thus, the age at first reproduction and life history strategy, which would incorporate elements of number of eggs and frequency of breeding are recommended as the seabird productivity attributes. These can be adapted from the current productivity attributes for age at maturity and fecundity.

With regard to susceptibility attributes for seabirds many of those used in the risk assessments reviewed required specific data to be collected and analysed, including raw data on fisheries and seabird distribution (WCPFC attribute on susceptibility – spatial component), bycatch rate (WCPFC attribute on susceptibility – vulnerability component) and observer data on number of birds present and attacking hooks (Uruguay attribute on access to bait) (Jimenez et al 2012, Waugh et al 2012). As this information would not necessarily be available in all cases, and for spatial data may require the assessment team to perform these analyses themselves, they are not recommended for inclusion.

Other attributes reviewed including behavioural susceptibility to capture (ICCAT attribute) and post-capture mortality (Uruguayan attribute) were considered appropriate, although the thresholds may need to be revised. The first is scored high or low risk (no medium category) based on information about the tendency of specific birds to follow fishing vessels and relative incidence of bycatch of that species in the gear type, either in the ICCAT area or other fisheries (Tuck et al 2011). The thresholds could be amended to include species/gear behaviours and/or level of bycatch incidence, if known, in the fishery.

Another attribute used in the Uruguayan assessment was hook selectivity. This was developed specifically for longline encounters with albatross and petrels and compared the culmen (bill) length to the front length of hook to determine if the bird was likely to be retained by the hook. This is too specific to apply across MSC fisheries but modifying the current selectivity attribute to account for a number of different selectivity scenarios like this could be useful. For example, a matrix approach with default scores for specific species group and gear scores could be developed in consultation with experts.

Although not reviewed as a specific PSA approach, a risk analysis performed for diving seabirds interacting with gillnets undertaken by Sonntag et al (2012) considered diving and aggregation behaviour of the different birds on the likelihood of their interacting with gillnets. This type of information could be considered in the current encounterability attribute, again possibly with a risk matrix containing default scores.

Cetacean-specific attributes

Although there are two PSA assessments specific to cetaceans, they use the same set of attributes (Brown 2013, Brown 2015). Productivity attributes that could be useful for the MSC PSA include age at female sexual maturity, oldest reproducing female and inter-calving interval. Calf survival was an attribute used but not recommended because in general adult survival has more influence on population growth rate than calf survival. Population trend was another attribute not recommended because it is not necessarily an indicator of population growth in the absence of impact – there may be instances where a highly productive population is decreasing due to other factors. If these factors include bycatch mortality, then it would be considering an element of susceptibility rather than productivity. Other attributes better capture intrinsic factors influencing population growth.

The age at female sexual maturity could be included in the current age at maturity attribute. As all marine mammals have one live young, the attribute on inter-calving interval – or breeding frequency – could be applied to capture variation in growth rate. Finally, oldest reproducing female could replace the current PSA attribute on maximum age since many cetacean species experience reproductive senescence and may not breed their whole lives.

These additional productivity attributes are based on cetaceans, so if pinnipeds and sirenians were also included in the same grouping, the thresholds would need to be determined on the range across these species groups and tested.

For susceptibility, the titles of the attributes are similar as for the current PSA but they are assessed differently. Availability is similar to areal overlap but the thresholds are specific to the NE Atlantic; encounterability uses a spatial, habitat-use approach rather than a vertical overlap approach; selectivity is based on potential for capture; and potential for lethal encounter is similar to post-capture mortality but allows for cases where the animal may be injured by the gear (Brown et al 2013, 2015). Of these, the availability attribute is coarser, but potentially easier to apply than the one currently used in the PSA. The thresholds, although specific to the Atlantic (High: NE Atlantic distribution/subspecies/subpopulation. Medium: N Atlantic distribution/subspecies/subpopulation. Low: Atlantic distribution), could be adapted more widely. It also allows for the presence of subspecies or subpopulations.

The selectivity attribute is quite general but Brown et al 2013 compiled a species/gear type selectivity matrix that was reviewed by bycatch experts to come up with scores. Scoring was based on opinion as to whether a particular gear could feasibly capture a particular species assuming it encountered it and was informed, in part, by knowledge of the occurrence of bycatch of that species in that gear, or of similar species in similar gears. For susceptibility, the potential for entanglement of larger species, such as humpback whales, in the lines supporting gear was considered along with the potential for capture in the main body of the gear. If this approach was used in MSC, specific requirements and guidance could be provided to ensure such an approach is auditable. Or, as suggested for seabirds, the MSC could develop a matrix of default scores, with expert involvement, and allow assessment teams to vary from this matrix in specific cases, such as when mitigation measures are applied.

The potential for lethal encounter is a useful attribute to replace the post-capture mortality attribute as it considers both potential for injury and death. In many cases, injured animals are returned but their ultimate fate is unknown, so this approach could add precaution to this attribute.

Sea turtle-specific attributes

Two assessments used a PSA method specific to sea turtles (Angel et al 2014, Nel et al 2013). Attributes used in both cases are similar. Additional productivity attributes that could be useful for the MSC PSA include number of breeding (nesting) females, age at maturity, hatchling success, emergence success, mean clutch size, nests/female/season, and remigration interval. As with cetaceans, the population trend attribute was not selected.

A number of the attributes relate to fecundity and could be combined in a similar way as is done for the seabirds, or a couple of the attributes judged most important could be selected.

For the susceptibility attributes, the overlap is useful for MSC, but they have calculated this on number of squares of species overlap in RFMO area (Angel et al 2014, Nel et al 2013). Not all fisheries will have specific grid cells to do this, but the method itself could be included as an example in guidance of how to estimate % areal overlap when this information is available. Other susceptibility attributes such as confidence estimate in distribution data and spawner biomass (number of breeding females) were not selected because they do not relate to the catchability of the species specifically. The final attribute on bycatch estimate relative to natural mortality requires data on bycatch mortality and, as it already scales the mortalities by a productivity value rather than relying on the overall risk score to do this.

Sea snake-specific attributes

Only one assessment specific to sea snakes was carried out (Milton 2001). For productivity they use maximum weight, % of biomass removed, length at maturity, mortality index and annual fecundity. Of these, maximum weight, length at maturity and annual fecundity are the most useful, but both the weight and length may not be necessary as they are both proxies for size. The % of biomass removed and mortality index were not recommended as they are more related to susceptibility and require bycatch data, which may not always be available.

Of the susceptibility attributes, preferred habitat (similar to encounterability-habitat), survival (similar to post-capture mortality) and range (similar to areal overlap) are most useful. There is an attribute on whether the species is caught in day or night but it is not clear why one would be more susceptible than the other – it could be related to when this specific fishery operates. Diet is also included to account for whether the species would be attracted to the trawl grounds, but this could be considered as part of encounterability in terms of likelihood to increase encounterability due to species behaviour (attraction to bait or discards).

Other general assessment attributes

Other assessments undertaken included out of scope species but were not necessarily specifically designed for them. Of these, some had a composite approach to scoring productivity and susceptibility, e.g. using reproductive strategy and length at maturity and maximum length to get an overall productivity score rather than assigning each attribute a score and calculating overall risk (Arrizabalaga et al 2011, Kirby 2006, Murua et al 2009). The MSC could consider an approach like this in future, but it is not clear that changing to this method would have any advantage over the current approach. These are therefore not considered further.

The remaining assessments include an EREAF assessment from Australia (as all use the Hobday et al 2007 approach and attributes, only one example of application was selected), a risk assessment for the SW Indian Ocean and a risk assessment for Baja, Mexico. Attributes for all of these assessments are similar, being based on the Hobday et al 2007, 2011 approach (Daly et al 2007, Kiszka 2012, Micheli et al 2014). Additional productivity attributes in the SW Indian Ocean approach included range, global population size, habitat characteristics and diet (Kiszka 2012). However, none of these were selected either because they were either not relevant to, or of smaller influence, on population growth rate. All of the other productivity attributes have already been discussed as they are similar to the current MSC PSA approach.

For susceptibility, the attributes for the Mexico and Australia risk assessments have already been discussed as they are similar to the current MSC PSA approach. The thresholds used were specifically calculated for those particular ecosystems. The attributes for the SW Indian Ocean approach include as different attributes mean regional bycatch incidents and commercial value. The first requires specific data, and the second may not be relevant for out of scope species in most instances. Therefore, neither are selected.

Recommendations

General PSA approach

Before deciding on the final selection of attributes and thresholds to be applied, some thought needs to be given to the overall objective associated with using the PSA for out of scope species. In general, PSA was created as a tool to allow measuring of relative risk, e.g. the risk of a management objective not being achieved, to allow prioritisation of further analysis or management action for higher risk species (Hobday 2011). In the context of MSC, the objective is slightly different. It is effectively being used to determine a level of sustainability and may differ by performance indicator. One of the MSC objectives for ETP species is to ensure that each fishery is not hindering recovery of those species (PI 2.3.1 outcome status). The PSA results, then, indicate the level of relative risk associated with not achieving that for each species but do not define how the risk categories relate to the probability of the fishery failing to achieve the objectives (Hordyk and Carruthers 2018). It would help create clarity around the use of the RBF, both for those applying it and those reviewing it, if the objectives of using the

RBF for each PI were specified, and the relationship between associated risk levels relates and sustainability levels in the default tree made clear.

Recommendation 1: Consider and clearly specify the objectives for using the PSA, as linked to PIs in the default assessment tree

It is important that the RBF is precautionary for all species groups for which it is applied. The MSC intention is that incorporating a level of precaution provides an incentive to use the conventional methods (i.e. default tree) when data is available. The Guidance to the MSC Fisheries Certification Process (v2.1) indicates that “precautionary levels can be defined as the probability that the resulting RBF score is greater than the score obtained if using the default assessment tree (DAT).” RBF parameters have previously been calibrated against the default tree. For PI 2.2.1, the probability that the RBF score is greater than the DAT is ‹0.2, or resulting scores are on average less than 10 scoring points above PI 2.1.1. For PI 2.3.1, the probability that the RBF score is greater than the DAT is ‹0.05 (MSC 2018b). However, it is not clear if the previous calibration was conducted using a range of out of scope species in these PIs. Given the outputs of the comparison between default and PSA scores undertaken here (although also noting caveats, see section 3.1), the current levels of precaution for out of scope species may not be appropriate.

Recommendation 2: Undertake new calibration precaution level in RBF scores for PI 2.2.1 and 2.3.1, using a range of out-of-scope species

Another topic that should be considered by MSC is specificity in defining the unit that is being assessed. Ideally, this should be the smallest relevant unit – a population. However, specific populations may not be defined for many out of scope species (indeed this is the case with IUCN Red List assessments for many out of scope species). Marine mammal stock assessments and sea turtle regional management units are two cases where distinct populations have been defined, but guidance could be provided to ensure that the assessment team are being as precautionary as possible when identifying the unit.

Recommendation 3: Specify that scoring of PSA attributes should be done at the smallest relevant unit, a population ideally

There are some aspects of the current default tree PIs that are not fully captured when the RBF is applied. For Principle 2 species generally this includes consideration of unobserved mortality, including impacts from IUU fishing, animals that are injured and subsequently die as a result of coming into contact with fishing gear, animals that are stressed and die as result of attempting to avoid capture in gear and ghost fishing (MSC 2018b). None of this is directly captured in the current attributes, but there may be options for including them in a revised PSA or associated guidance. For example, the attribute used for a cetacean risk assessment in the NE Atlantic instead of post-capture mortality is ‘potential for lethal encounter’ (Brown et a 2013). The thresholds consider likelihood that the interaction will result in death, but also consider if it will result in injury. Using this attribute would cover one element of unobserved mortality. Other elements could be included by providing guidance, e.g. encounterability and selectivity considering active gears but also ghost gear interactions, areal overlap including consideration of IUU fishing.

Both PIs 2.2.1 and 2.3.1 have an element of cumulative impact included, which is not be captured in the PSA for out of scope species. Depending on the outcome of the ETP review in the next standard review, it should be considered to include all MSC UoAs in evaluation of susceptibility for out of scope species.

Within PI 2.3.1, the default tree also requires an assessment of indirect impact on the species, but this is not included in the PSA. This is one reason why the scores for the PI for 2.3.1 do not correspond directly with the outputs of the PSA (see section 3.1). As the Fishery Standard Review may include review and/or revision of the ETP requirements, this should be considered alongside that review. If the indirect impacts are maintained in the default tree PI, it may be worth considering how they could be applied using the RBF. There is currently a Scale Intensity Consequence Analysis (SICA) developed for the ecosystem PI, so elements of this could be brought into the ETP RBF. Consultation with experts in ecosystem impacts could be consulted to develop this. Altneratively, as the ecosystem PI should already capture indirect effects of the fishery, the default tree scoring issue could be dropped. In that case, no change would be needed to the PSA approach to include indirect impacts.

Recommendation 4: Review elements of PIs where out of scope species are scored that are not currently captured in PSA and consider how they could be incorporated (if deemed relevant) in PSA attributes, thresholds or associated guidance

Attribute selection and species grouping

Table 11 identifies the attributes that are recommended for further evaluation for each species group based on the results of this review. The susceptibility attributes are the same for all species but would require further elaboration in some cases related to species behaviour, size and gear type they are interacting with.

Many of the attributes of the current PSA were shown in this review to have the same score (e.g. Fecundity and Reproductive strategy) and others were shown to not be relevant or practical for the species group in question (e.g. size attributes for seabirds). Hordyk and Carruthers (2018) also found that the PSA scoring may be over-parameterized, with irrelevant or correlated attributes lowering the predictive capacity of the overall approach. Decreasing the overall number of attributes, if doing so would ensure robust and precautionary assessments, would also be beneficial in terms of the time spent in conducting the RBF and reducing associated costs of application. It is recommended to evaluate the PSA with different numbers of attributes, and for multiple species in each species group, to determine the optimum number of attributes to get reliable results.

It would also be useful to consider whether any default scoring could be provided for the encounterability and selectivity scores based on species group and gear characteristics (e.g. for selectivity of longline, hook type and likelihood for species group to be retained). This matrix approach could be similar to that used in the MSC Consequence Spatial Analysis for habitats when scoring removability of biota and substratum attributes for different gear types. Deviations from the default could be allowed if justified, e.g. if there were modifications made to the gear or mitigation measures. A workshop with experts on species-gear interactions for each of the species groups could be held to create the matrices. If the matrix approach was not determined to be appropriate, then the workshop outputs could be included as guidance for approaching scoring of susceptibility attributes for different gears and out of scope species groups.

The recommendations on attributes described in Table 11 provide a “straw man” of attributes that could be analysed in more detail.

Recommendation 5: Test the applicability and precaution of the attributes proposed in Table 11, including whether additional attributes are needed to ensure robust and reliable results. Hold a workshop to develop default scores and guidance for species/gear interactions for encounterability and selectivity attributes.

Before deciding on thresholds to apply, consideration is needed on whether the thresholds should be applicable across all species, as they are in the current MSC analysis and other multi-species assessments including Hobday et al 2011, or tailored to be applicable for each species groups as in the species-specific PSAs reviewed. In the former approach, some productivity scores would be high risk for all out of scope species (e.g. fecundity, where all species have one offspring), whereas in the latter there could be differences in the life history better captured to better evaluate the relative risk within a species group (e.g. fecundity with number offspring coupled with frequency of breeding parameters) – so some species might have higher and some lower than current PSA risk scores. In the attributes proposed in Table 11, the approach with differences in species group life history parameters is recommended. However, it is also recommended that this be compared with outputs from scores where multiple species groups are included before confirming a final approach.

It is noted that SeaFood Watch, rather than apply a PSA, automatically assign a high inherent vulnerability score for sharks, sea turtles, seabirds marine mammals and corals. The high score is allowed to be overridden in cases where there is evidence that the population’s status is not of high concern (Monterey Bay Aquarium 2019). However, it is not clear what criteria and information sources would be used to determine this and could lead to inconsistent outcomes.

Before the final thresholds are defined, it is proposed to collect the relevant information on known bycatch species in each group (in light of above, using different grouping levels) and to undertake a Cluster analysis or similar method to group the risk scores (e.g. as undertaken by Brown et al 2013 for cetaceans). The outputs of these analyses can then be reviewed by relevant experts on each taxa, ideally in a workshop setting before decision is reached on final species grouping and thresholds. It is recommended that this be applied for all out of scope species groups reviewed here, except for amphibians. There was only one record found of bycatch of amphibians in fisheries in the literature review, and bycatch is not considered one of the main threats to this species group. Therefore, the focus should be on other taxa.

A division of some species groups is recommended here, but further refinement may be needed once the taxa-specific analysis and expert review is completed.

Recommendation 6: Collect relevant life history information on range of out-of-scope species within each group, except for amphibians, and undertake Cluster analysis or similar approach to define thresholds and finalise species groupings

Table 10 Attributes and thresholds recommended for out of scope species groups (except amphibians)

Species group	Attribute	P or S	Thresholds	Rationale
Seabirds (all)	Age at first reproduction	P	Calibrate based on range of known bycatch species	Captures variation in life history characteristics within species group Explanatory power for population growth Used in seabird-specific risk assessments
Seabirds (all)	Fecundity	P	Low risk: >1 egg, annual breeder Medium risk: 1 egg / annual breeder High risk: 1 egg / biannual breeder	Captures variation in life history characteristics within species group Explanatory power for population growth Used in seabird-specific risk assessments – developed mainly for albatross and petrel species but likely to apply more widely
Marine mammals (Cetaceans, Pinnipeds, Sirenians)	Age at first reproduction (female sexual maturity)	P	Calibrate based on range of known bycatch species – determine if can group all marine mammals or keep separate	Captures variation in life history characteristics within species group Explanatory power for population growth Used in cetacean-specific risk assessments
Marine mammals (Cetaceans, Pinnipeds, Sirenians)	Fecundity (inter-calving interval / breeding frequency)	P	All have one young. For cetaceans: High risk >3.5 years, Medium: 2.6-3.5, Low <=2.5 years Need to calibrate for other groups.	Captures variation in life history characteristics within species group (traits not captured by difference in size, e.g. Maui's dolphin) Explanatory power for population growth Used in cetacean-specific risk assessment, so thresholds already cover wide range of species (need to calibrate for other groups)

Species group	Attribute	P or S	Thresholds	Rationale
Marine mammals (Cetaceans, Pinnipeds, Sirenians)	Oldest reproducing female	P	For cetaceans: High risk >=61 years, Medium: 45-60 years; Low risk <=44 years Need to calibrate for other groups.	Captures variation in life history characteristics within species group and considers reproductive senescence (rather than using maximum age) Explanatory power for population growth Used in cetacean-specific risk assessments so thresholds already cover wide range of species (need to calibrate for other groups)
Sea turtles	Age at first reproduction	P	Calibrate based on range of known bycatch species	Captures variation in life history characteristics within species group Explanatory power for population growth Used in sea turtle-specific risk assessments
Sea turtles	Fecundity	P	Reproductive output per female per season (need clutch size, number of nests per season and remigration interval) e.g. low = (90 eggs x 4 nests)/4 years = <90 Medium = 90-277 High = (120 eggs *6 nests)/2.6=>277	Captures variation in life history characteristics within species group Explanatory power for population growth Combines multiple attributes used in sea turtle-specific risk assessments (need to test that the thresholds are still applicable as such once combined)
Sea turtles	Number of nesting females in RMU	P	Low p (high risk): very small & small; Medium: medium & large: High: very large RMU-specific guidance can be provided (data available)	Captures variation in life history characteristics within species group Explanatory power for population growth Used in sea turtle-specific risk assessments
Sea snakes	Age at maturity	P	Calibrate based on range of known bycatch species	Captures variation in life history characteristics within species group Explanatory power for population growth Used in sea snake -specific risk assessments

Species group	**Attribute**	**P or S**	**Thresholds**	**Rationale**
Sea snakes	Annual fecundity	P	Calibrate based on range of known bycatch species	Captures variation in life history characteristics within species group Explanatory power for population growth Used in sea snake-specific risk assessments
Sea snakes	Average maximum size	P	Calibrate based on range of known bycatch species. Consider if use length or weight.	Captures variation in life history characteristics within species group Explanatory power for population growth Used in sea snake-specific risk assessments
All out of scope	Areal overlap	S	As in current PSA. Provide specific requirements on how to select e.g. the season where greatest overlap occurs. Provide guidance on methods for estimating distribution of different species groups (e.g. Small et al 2013 recommendations for seabirds).	Maintains attributes of catchability as set out in Walker (2005) but guidance will allow more consistent and precautionary approaches by CABs
All out of scope	Encounterability	S	Develop a default set of scores in a species/gear matrix based on behavioural and gear-based factors, e.g. for gillnets could be vertical overlap vs for pelagic longline attraction to bait at surface for surface feeders. Or make clear that all air-breathing species will have high risk score as per Hobday et al 2007. Allow consideration of any mitigation measures. If they are 'best practice' as identified by ACAP, for example, may reduce risk score. Add guidance on how to score if ghost fishing may occur in fishery	Maintains attributes of catchability as set out in Walker (2005) but guidance will allow more consistent and precautionary approaches by CABs Includes one of the unobserved mortality elements

Species group	Attribute	P or S	Thresholds	Rationale
All out of scope	Selectivity	S	Develop a default set of scores in a species/gear matrix based on likelihood of gear to retain species if encountered. Allow modifications under certain conditions (e.g. different mesh sizes, hook shapes etc)	Maintains attributes of catchability as set out in Walker (2005) but guidance will allow more consistent and precautionary approaches by CABs
All out of scope	Potential for lethal encounter	S	High risk: interaction with gear likely to result in death; Medium: interaction with gear likely to result in injury; low: interaction with gear unlikely to result in injury or death	Maintains attributes of catchability as set out in Walker (2005) but guidance will allow more consistent and precautionary approaches by CABs Includes one of the unobserved mortality elements

SWOT analysis

A Strengths, Weaknesses, Opportunities, Threats (SWOT) analysis was undertaken for each of the recommendations. Results are presented in Table 12.

Table 11 SWOT Analysis of Recommendations compared to no change (or only guidance added)

Recommendation	Strengths	Weaknesses	Opportunities	Threats
Recommendation 1: Consider and clearly specify the objectives for using the PSA, as linked to PIs in the default assessment tree	Provides clearer understanding for those undertaking PSA and stakeholders on how default tree and RBF is linked Justifies level of precaution needed	Highlights that PSA is not direct sustainability measure	Highlights importance of precautionary approach, so some stakeholders may support its use Could allow development of other metrics to better evaluate sustainability directly for data-deficient, out of scope species	If not considered direct sustainability measure, some stakeholders may not support use of approach as method of assessing MSC standard

Recommendation	Strengths	Weaknesses	Opportunities	Threats
Recommendation 2: Undertake new calibration precaution level in RBF scores for PI 2.2.1 and 2.3.1, using a range of out-of-scope species	Ensures overall risk scores are aligned such that they are more precautionary than default tree PIs	If level of precaution increased, may mean harder for fisheries to pass or pass without condition	If increase precaution, some stakeholders will see this as a positive step to increase bar If more fisheries get conditions, could lead to more on the water improvements	If increase precaution, some stakeholders will see this as a negative step to increase bar More conditions are more costly for clients
Recommendation 3: Specify that scoring of PSA attributes should be done at the smallest relevant unit, a population ideally	This is consistent with default tree, but is not always captured effectively in default tree or RBF	Not all species can be identified to population level, so some level of expert judgement will still be included	May incentivise groups to better define populations, e.g. use of Regional Management Units for sea turtles	Risk with expert judgement that there may be inconsistency in how this is approached particularly if only guidance is provided Also, scoring at species level can be less precautionary when e.g. scoring areal overlap
Recommendation 4: Review elements of PIs where out of scope species are scored that are not currently captured in PSA and consider how they could be incorporated (if deemed relevant) in PSA attributes, thresholds or associated guidance	Creates more consistency between default tree and RBF Ensures sustainability issues other than direct, observed mortalities are considered	Could make assessment more onerous May not be information available to assess this adequately in data-deficient situations	May incentivise groups to consider all sources of impact If more fisheries get conditions because these elements are considered, it could lead to more on the water improvements	Potential for more conditions as more elements considered – this is more costly for clients

Recommendation	Strengths	Weaknesses	Opportunities	Threats
Recommendation 5: Test the applicability and precaution of the attributes proposed in Table 11, including whether additional attributes are needed to ensure robust and reliable results & Recommendation 6: Collect relevant life history information on range of out-of-scope species and undertake Cluster analysis or similar approach to define thresholds and finalise species groupings	Attributes and thresholds are more appropriate to species and reflect the key drivers of intrinsic population grown unique to each group and catchability of that species in the assessed fishery Clearer requirements and guidance (including possible default scores for some susceptibility attributes based on species and gear characteristics) should result in more consistent scoring	Allowing for risk to be assessed within species groups (in this relative risk process) may result in some lower and some higher risk scores than in current method, and depending on which, might make certain stakeholders more or less concerned Still a large element of expert judgement in this methodology – particularly for susceptibility attributes, so it is very dependent on having the 'correct' stakeholders in the room	Opportunity to adapt attributes for each group as new approaches are trialled or there is improved understanding of species life history or fisheries catchability	If requirements are too prescriptive, may unduly punish some fisheries that have e.g. mitigation measures in place. If requirements not prescriptive enough can lead to inconsistent or incorrect outcomes
No change to current PSA requirements (but may provide some interpretations/ guidance)	Does not require revision of requirements Could provide needed guidance on how to use current PSA for out of scope species	Attributes not all logical for out of scope species – may give higher risk scores than needed where information is limited	Could provide opportunity for calibration discussion and better understanding of RBF approach among CABs	Where attributes are not precautionary or treated in precautionary way (even if CABs are following guidance), could result in scores that are not precautionary enough, and undermine the MSC standard

Conclusion

In conclusion, the review of MSC PSA compared to default tree scores, despite caveats, indicates that the current PSA approach is not precautionary when applied to out of scope species. In addition, the review of the only current application of the PSA for out of scope species in the *[text redacted]* shows that it is challenging to apply the current PSA for out of scope species, which can lead to incorrect or inconsistent outcomes. The overall review of the logic of attributes considering the life history characteristics of the different out of scope species also showed that many of the current attributes and thresholds are either inappropriate or redundant. To address this, a number of recommendations were made to review and revise attributes (Table 11). It is suggested that each species group have two to three productivity attributes (compared to current seven) and the four susceptibility attributes currently used are retained but that thresholds are redefined and requirements specific to gear and out of scope species interactions are included.

Other recommendations were also made about considering out of scope species PSA going forward, including linking objectives and risk levels for PSA to the default tree, re-calibrating the level of precaution ensuring that out of scope species are adequately covered, defining the unit (e.g. population) to be assessed and considering elements from the default tree like unobserved mortality and indirect impacts in the PSA.

References

Abraham ER, Neubauer P, Berkenbusch K, Richard Y. 2017. Assessment of the risk to New Zealand marine mammals from commercial fisheries. New Zealand Aquatic Environment and Biodiversity Report 189. Wellington: MPI. 123pp.

[text redacted]

Anderson ORJ, Small CJ, Croxall JP, Dunn EK, Sullivan BJ, Yates O, Black A. 2011. Global seabird bycatch in longline fisheries. Endangered Species Research 14: 91-106.

[text redacted]

Angel A, Nel R, Wanless RM, Mellett B, Harris L, Wilson I. 2014. Ecological Risk Assessment of Sea Turtles to Tuna Fishing in the ICCAT Region. Collect. Vol. Sci. Pap. ICCAT, 70(5):2226–59.

Arrizabalaga H, de Bruyn P, Diaz GA, Murua H, Chavance P, de Molina AD, et al. 2011. Productivity and susceptibility analysis for species caught in Atlantic tuna fisheries. Aquatic Living Resources (1):1–12.

[text redacted]

Breen P, Brown S, Reid D, Rogan E. 2017. Where is the risk? Integrating a spatial distribution model and a risk assessment to identify areas of cetacean interaction with fisheries in the northeast Atlantic. Ocean & Coastal Management 136: 148-155.

Brown SL, Reid D, Rogan E. 2013. A risk-based approach to rapidly screen vulnerability of cetaceans to impacts from fisheries bycatch. Biol Conserv. 168:78–87.

Brown SL, Reid D, Rogan E. 2015. Spatial and temporal assessment of potential risk to cetaceans from static fishing gears. Marine Policy 51: 267-280.

[text redacted]

Casale P & Heppell SS. 2016. How much sea turtle bycatch is too much? A stationary age distribution model for simulating populatin abundance and potential biological removal in the Mediterranean. Endangered Species Research 29: 239-254.

Courtney AJ, Schemel BL, Wallace R, Campbell MJ, Mayer DG, Young, B. 2010. Reducing the impact of Queensland's trawl fisheries on protected sea snakes. Report to the Fisheries Research and Development Corporation Project No. 2005/053. Queensland: Fisheries Research and Development Corporation. 121pp.

Croxall JP, Butchart SHM, Lascelles B, Stattersfield AJ, Sullivan B, Symes A, Taylor P. 2012. Seabird conservation status, threats and priority actions: a global assessment. Bird Conservation International 22: 1-34.

Croxall JP & Rothery P. 1991 Population regulation of seabirds: implications of their demography for conservation. In: Perrins CM; Lebreton J-D; Hirons GM, (eds.) Bird population studies: relevance to conservation and management. Oxford, Oxford University Press, 272-296.

Currey RJC, Boren LJ, Sharp BR, Peterson D. 2012: A risk assessment of threats to Maui's dolphins. Ministry for Primary Industries and Department of Conservation, Wellington. 51 pp.

Curtis KA & Moore JE. 2013. Calculating reference points for anthropogenic mortality of marine turtles. Aquatic Conservation: Marine and Freshwater Ecosystems 23: 441-459.

Daley R, Webb H, Hobday A, Timmiss T, Walker T, Smith T, Dowdney, Williams A. 2007. Ecological Risk Assessment for the Effects of Fishing. Report for the automatic longline sub-fishery of the Southern and Eastern Scalefish and Shark Fishery. Report for the Australian Fisheries Management Authority, Canberra.

Damortharan P, Arumuguam M, Vijayalakshmi S, Balasubramanian T. 2010. Diversity, biology and ecology of sea snakes (Hydrophiidae) distributed along the Parangipettai coast, southeast coast of India. International Journal of Current Research 4: 62-69.

Duffy, L & Griffiths S. 2017. Resolving potential redundancy of productivity attributes to improve ecological risk assessments. Inter-American Tropical Tuna Commission Scientific Advisory Committee. Eighth Meeting, La Jolla, CA. 8-12 May 2017.

Eckert KL, Wallace BP, Frazier JG, Eckert SA, Pritchard PCH. 2012. Synopsis of the Biological Data on the Leatherback Sea Turtle (Dermochelys coriacea). Biological Technical Publication BTP-R4015-2012. US Fish & Wildlife Service. 172pp.

Fry GC, Milton DA, Wassenberg TJ. 2011. The reproductive biology and diet of sea snake bycatch of prawn trawling in northern Australia: characteristics important for assessing the impacts on populations. Pacific Conservation Biology 7: 55-73.

Gagné TO, Hyrenbach KD, Hagemann ME, Bass OL, Pimm SL, MacDonald M, Peck B, Van Houtan KS. 2018. Seabird Trophic Position Across Three Ocean Regions Tracks Ecosystem Differences. Front. Mar. Sci. 5:317.

Gaillard J-M, Pontier D, Allaine D, Lebreton, JD, Trouvilliez J, Clobert J. 1989. An analysis of demographic tactics in birds and mammals. Oikos 56: 59-76.

[text redacted]

Hammill MO, Blanchfield P, Higdon JW, Steward DB, Ferguson SH. 2016. Estimating abundance and total allowable removals for walrus in Foxe Basin. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/014. 20pp.

Heppell SS. 2005. Development of alternative quantitative tools to assist in jeopardy evaluation for sea turtles. Final Report for the Southeast Fisheries Science Center. Department of Fisheries and Wildlife, Oregon State University.

Hobday AJ, Smith ADM, Stobutzki IC, Bulman C, Daley R, Dambacher JM, et al. 2011. Ecological risk assessment for the effects of fishing. Fish Res. 108(2–3):372–84.

Hobday AJ, Smith A, Webb H, Daley R, Wayte S, Bulman C, et al. 2007. Ecological Risk Assessment for Effects of Fishing: Methodology. Canberra: Australian Fisheries Management Authority R04/1072.

Hoque B & Saidapur SK. 1994. Dynamics of oogenesis in the tropical anuran *Rana tigrina* (Amphibia: Ranidae) with special reference to vitellogenic cycles in wild-caught and captive frogs. Journal of biosciences 19(3): 339-352.

Hordyk, A.R., Carruthers, T.R. (2018) A quantitative evaluation of a qualitative risk assessment framework: Examining the assumptions and predictions of the Productivity Susceptibility Analysis (PSA). PLOS One 13(6): e0198298.

Jiménez, S., Domingo, A., Abreu, M., & Brazeiro, A. (2012) Risk assessment and relative impact of Uruguayan pelagic longliners on seabirds. Aquatic Living Resources, 25(4), 281–295.

Keyfitz, N. 1968. “Introduction to the Mathematics of Population,'' Addison-Wesley, Reading, MA.

Kirby, D.S. 2006. Ecological risk assessment for species caught in WCPO Tuna fisheries: inherent risk as determined by productivity-susceptibility analysis. Pap EB WP–1 2nd Meet Sci Comm West Cent Pacific Fish Comm WCPFC–SC1, Manila, Philipp.; 7–18

Kiszka JJ. 2012. An Ecological Risk Assessment (ERA) for marine mammals, sea turtles and elasmobranchs captured in artisanal fisheries of the SW Indian Ocean based on interview survey data. IOTC WPEB 2012. 14pp.

Lemen CA, Voris HK. 1981. A Comparison of Reproductive Strategies among Marine Snakes. Journal of Animal Ecology 50: 89-101.

Lennox RJ, Twardek WM, Cooke SJ. 2018. Observations of Mudpuppy (*Necturus maculosus*) bycatch in a recreational ice fishery in northern Ontario. Canadian Field-Naturalist 132(1): 61-66.

Lewison RL, Crowder LB, Read AJ, Freeman SJ. 2004. Understanding impacts of fisheries bycatch on marine megafauna. Trends in Ecology and Evolution 19(11): 598-604.

Lotka A. 1907. Relation between birth rates and death rates. Science 26: 21-22.

MSC. 2018a. Fisheries Certification Process v2.1. London: Marine Stewardship Council.

MSC. 2018b. Guidance to the Fisheries Certification Process v2.1. London: Marine Stewardship Council.

Mateo I, Ennis GP, Dunne E. 2018. Public Certification Report for Newfoundland & Labrador snow crab. Dundalk, IE: SAI Global. 257pp.

Micheli F, De Leo G, Butner C, Martone RG, Shester G. 2014. A risk-based framework for assessing the cumulative impact of multiple fisheries. Biol Conserv.; 176:224–35.

Milton, DA. 2001. Assessing the susceptibility to fishing of populations of rare trawl bycatch: Sea snakes caught by Australia’s northern prawn fishery. Biol Conserv. 2001, 101(3):281–90.

Monterey Bay Aquarium. 2019. Seafood Watch Standard for Fisheries, Public comment period – 2. Online: https://www.montereybayaquarium.org/-/m/C73BE3D0AEA244D8A29BA9DD11CAE920.pdf?mpweb=1321-2440-619140 (accessed 2 September 2019).

Murua H, Arrizabalaga H, Julia Hsiang-Wen Huang J, Romanov E, Bach P, de Bruyn P, et al. 2009. Ecological Risk Assessment (ERA) for species caught in fisheries managed by the Indian Ocean Tuna (IOTC): a first attempt.

Nel R, Wanless RM, Angel A, Mellet B, Harris L. 2013. Ecological Risk Assessment and Productivity Susceptibility Analysis of sea turtles overlapping with fisheries in the IOTC region. Unpublished Report to IOTC and IOSEA Marine Turtle MoU. 99pp.

Nisbet ICT. 1989. Long-Term Ecological Studies of Seabirds. Colonial Waterbirds 12(2): 143-147.

Pauly D, Trites AW, Capuli E, Christensen V. 1998. Diet composition and trophic levels of marine mammals. ICES Journal of Marine Science, 55: 467–481.

[text redacted]

Rasmussen AR, Murphy JC, Ompi M, Gibons JW, Uetz P. 2011. Marine Reptiles. PLoS ONE 6(11): e27373.

Reeves RR, Folkens PA et al. 2002. National Audubon Society Guide to Marine Mammals of the World. New York: AA Knopf. 527pp.

Reichart, HA. 1993. Synopsis of Biological Data on the Olive Ridley Sea Turtle *Lepidochelys olivacea* in the Western Atlantic. Miami: National Marine Fisheries Service Southeast Fisheries Science Center. 86pp.

Richard Y, Abraham ER. 2017. Assessment of the risk of commercial fisheries to New Zealand seabirds, 2006-07 to 2014-15. New Zealand Aquatic Environment and Biodiversity Report No. 191. Wellington: MPI.

Sharp BR. 2017. Spatially Explicit Fisheries Risk Assessment (SEFRA): A framework for quantifying and managing incidental commercial fisheries impacts on non-target species. In Aquatic Environment and Biodiversity Annual Review (AEBAR) 2017: A summary of environmental interactions between the seafood sector and the aquatic environment. Ministry for Primary Industries, New Zealand, 724 pp.

Shealer DA. 2002. Foraging behaviour and food of seabirds. In Schrieber EA, Burger J (Eds) Biology of Marine Birds. New York: CRC Press: 137-170.

Small C; Waugh SM; Phillips RA. 2013. The justification, design and implementation of Ecological Risk Assessments of the effects of fishing on seabirds. Marine Policy 37: 192-199.

Sonntag N, Schwemmer H, Fock HO, Bellebaum J, and Garthe S. 2012. Seabirds, set-nets, and conservation management: assessment of conflict potential and vulnerability of birds to bycatch in gillnets. ICES Journal of Marine Science 69: 578–589.

Sodhi NS, Bickford D, Diesmos AC, Lee TM, Koh LP, et al. 2008. Measuring the Meltdown: Drivers of Global Amphibian Extinction and Decline. PLoS ONE 3(2): e1636.

Stobutzki I, Miller M, Brewer D. 2001. Sustainability of fishery bycatch: a process for assessing highly diverse and numerous bycatch. Environmental Conservation 28(2):167–81.

Taylor BL, Chivers SJ, Larese J, Perrin WF. 2007. Generation length and percent mature estimates for IUCN assessments of cetaceans. Administrative report LJ-07-01. Southwest Fisheries Science Center, National Marine Fisheries Service.

Tuck GN, Phillips RA, Small C, Thomson RB, Klaer NL, Taylor F, … Arrizabalaga H. (2011) An assessment of seabird – fishery interactions in the Atlantic Ocean. ICES Journal of Marine Science, 68(8), 1628–1637.

Wade, PR. 1998. Calculating limits to the allowable human-caused mortality of cetaceans and pinnipeds. Marine Mammal Science 14(1): 1-37.

Walker TL. 2005. 13 Management measures. In Musick JA, Bonfil R (Eds.) Management techniques for elasmobranch fisheries. FAO Fisheries Technical Paper 474: 216-242.

Wallace BP, DiMatteo AD, Bolten AB, Chaloupka MY, Hutchinson BJ, et al. 2011. Global Conservation Priorities for Marine Turtles. PLoS ONE 6(9): e24510.

Wallace BP, Kot CY, DiMatteo AD, Lee T, Crowder LB, Lewison RL. 2013. Impacts of fisheries bycatch on marine turtle populations worldwide: toward conservation and research priorities. Ecosphere 4(3):40.

Warden ML. 2010. Bycatch of wintering common and red-throated loons in gillnets off the USA Atlantic coast 1996-2007. Aquatic Biology 10: 167-180.

Waugh SM, Filippi DP, Kirby DS, Abraham E, Walker, N. 2012 Ecological Risk Assessment for seabird interactions in Western and Central Pacific longline fisheries. Marine Policy, 36(4), 933–946.

Weimerskirch H. 2002 Seabird Demography and its Relationship with the marine Environment. In Biology of Marine Birds

Appendix 1 Productivity and Susceptibility scores per species group

Table A1.1 Productivity attribute scores by species group: seabirds

Species	**Sub-group**	**rmax**	**AM**	**MA**	**F**	**MS**	**SM**	**RS**	**TL**	**Overall P**
Black-browed albatross (*Thalassarche melanophris*)	Pelagic seabird	Campbell black browed: 0.058*	2	3	3	2	2	3	3	2.57
White-chinned petrel (*Procellaria aequinoctialis*)	Pelagic seabird	0.076*	2	3	3	2	2	3	3	2.57
Great shearwater (*Ardenna gravis*)	Pelagic seabird	Sooty shearwater : 0.088*	2	2	3	2	2	3	3	2.43
Common loon (*Gavia immer*)	Coastal seabird?	0.086-0.122**	2	2	3	2	2	3	3	2.43
Kelp Gull (*Larus dominicanus*)	Coastal seabird	0.142*	1	2	3	2	2	3	3	2.29
Marbled murrelet (*Brachyramphus marmoratus*)	Coastal seabird?	unknown	1	1	3	1	2	3	3	2.00

*rmax values from Richard et al 2017, used similar species where specific species not available

**estimated from data in Warden 2010

Table A1.2 Productivity attribute scores by species group: Marine mammals

Species	Sub-group	rmax	AM	MA	F	MS	SM	RS	TL	Overall P
North Atlantic right whale (*Eubalaena glacialis*)	Cetaceans	SA right whale: 0.068**	2	3	3	3	3	3	2	2.71
Short-beaked common dolphin (*Delphinus delphis*)	Cetaceans	0.04**	2	3	3	2	3	3	3	2.71
Steller sea lion (*Eumetopias jubatus*)	Pinnipeds	0.12*	2	2	3	3	3	3	3	2.71
Dusky dolphin (*Lagenorhynchus obscurus*)	Cetaceans	0.047**	2	3	3	2	2	3	3	2.57
South American sea lion (*Otaria flavescens*)	Pinnipeds	0.12*	2	2	3	3	3	3	3	2.57
Harbour porpoise (*Phocoena phocoena*)	Cetaceans	0.04*	2	2	3	2	2	3	3	2.43
Grey seal (*Halichoerus grypus*)	Pinnipeds	0.12*	1	3	3	2	2	3	3	2.43
South American fur seal (*Arctocephalus australis*)	Pinnipeds	0.12*	2	2	3	2	2	3	3	2.43

*Wade 1998 use 0.12 for all pinnipeds, 0.04 for all cetaceans. **mean values from Abraham et al 2017

Table A1.3 Productivity attribute scores by species group: Marine reptiles (Note rmax not included as value not found in literature review for these species)

Species	Sub-group	AM	MA	F	MS	SM	RS	TL	Overall P
Leatherback turtle (*Dermochelys coriacea*)	Sea turtle	3	3	3	2	2	2	3	2.57
Elegant sea snake (*Hydrophis elegans*)	Sea snake	1	2	3	2	2	3	3	2.29
Short-nosed sea snake (*Aipysurus apraefrontalis*)	Sea snake	2	2	3	1	2	3	2	2.14
Olive ridley turtle (*Lepidochelys olivacea*)	Sea turtle	2	2	2	1	2	2	2	1.86

Table A1.4 Productivity attribute scores by species group: Amphibians (Note rmax not included as value not found in literature review for these species)

Species	Sub-group	AM	MA	F	MS	SM	RS	TL	Overall P
Mudpuppy (Necturus maculosus)	Salamander	2	3	3	1	1	2	1	1.86
Goliath frog (Conraua goliath)	Frog	3*	3*	1	1	1	2	2	1.86
Eastern Tiger salamander / Waterdogs (*Ambystoma tigrinum*)	Salamander	1	2	2	1	1	2	1	1.43
Indian bullfrog (Hoplobatrachus tigerinus / Rana tigerinus)	Frog	1	1	2	1	1	2	2	1.43

*Default high risk score as no information found

Table A1.5 Susceptibility attributes and gear evaluated for seabird species

Species	Sub-group	Gear evaluated	AO	E	S	PCM	Overall S
White-chinned petrel (Procellaria aequinoctialis)	Pelagic seabird	Demersal longline	3	3	1	3	1.65
Common loon AKA Great northern diver (Gavia immer)	Diving seabird	Gillnet	3	2	1	3	1.43
Black-browed albatross (Thalassarche melanophris)	Pelagic seabird	Mid-water trawl	2	3	1	1	1.13
Great shearwater (Ardenna gravis)	Pelagic seabird	Mid-water trawl	1	3	1	1	1.05
Kelp Gull (Larus dominicanus)	Pelagic seabird	Mid-water trawl	1	3	1	1	1.05
Marbled murrelet (Brachyramphus marmoratus)	Diving seabird	Gillnet	1	1	1	3	1.05

Table A1.6 Susceptibility attributes and gear evaluated for marine mammal species

Species	Sub-group	Gear evaluated	AO	E	S	PCM	Overall S
Dusky dolphin (Lagenorhynchus obscurus)	Cetaceans	Mid-water trawl	2	3	2	3	1.88
Short-beaked common dolphin (Delphinus delphis)	Cetaceans	Mid-water trawl	2	3	2	3	1.88
Harbour porpoise (Phocoena phocoena)	Cetacean	Gillnet	3	1	3	3	1.65
North Atlantic right whale (Eubalaena glacialis)	Cetacean	Pots/traps	2	3	2	2	1.58
South American fur seal (Arctocephalus australis)	Pinnipeds	Mid-water trawl	3	3	2	1	1.43
South American sea lion (Otaria flavescens)	Pinnipeds	Mid-water trawl	2	3	2	1	1.28

Table A1.7 Susceptibility attributes and gear evaluated for reptile species

Species	Sub-group	Gear evaluated	AO	E	S	PCM	Overall S
Elegant sea snake (Hydrophis elegans)	Sea snakes	Otter trawl	1	3	3	2	1.43
Short-nosed sea snake (Aipysurus apraefrontalis)	Sea snakes	Otter trawl	2	3	1	2	1.28
Leatherback turtle (Dermochelys coriacea)	Turtles	Pelagic longline	1	3	1	2	1.13

Appendix 2 Other PSA attributes

Table A2.1 Attributes from PSA approaches applied to one or more out of scope species group. Medium blue highlight indicates that the attribute and threshold were both considered useful to consider for the MSC PSA. Lighter blue highlight indicates that either the was considered useful but the threshold was not.

Species group	Assessment (ref)	Geographical area	Gear(s)	P or S	Attribute	Attribute useful MSC (Y/N)	Threshold	Threshold useful MSC (Y/N)
Pelagic seabirds	WCPFC ERA for seabirds (Waugh et al 2012)	WCPFC	Longline	P	Fecundity Factors Index (FFI)	Y	Life-history strategy (annual breeding, multiple-egg clutches=1; annual-breeding, single-egg clutches=2; biennial breeding, single-egg clutches=3) and median age at first breeding (‹5years= 1, 5–7.5 years group= 2, ›7.5 years= 3).	Y
Pelagic seabirds	WCPFC ERA for seabirds (Waugh et al 2012)	WCPFC	Longline	S	Susceptibility	N	Product of fishing effort (number of hooks in 5x5 squares for period 2002-2009 from WCPFC database) and normalised species distributions (i.e. proportion of a species' range). This was weighted with the vulnerability (V is equivalent to the average number of birds of a particular taxon group caught per 1000 longline sets).	N/A
Pelagic seabirds	ICCAT ERA for seabirds - objective 1 (Tuck et al 2011)	ICCAT	Longline	P	Life history strategy	Y	High risk: Biennial breeder, single egg, Medium: annual breeder, single-egg clutch, Low: Annual breeder, multiple-egg clutch	Y
Pelagic seabirds	ICCAT ERA for seabirds - objective 1 (Tuck et al 2011)	ICCAT	Longline	S	IUCN status	N	Critically endangered/Endangered=3, Vulnerable=2, Near Threatened=1, and Least Concern=0	N/A
Pelagic seabirds	ICCAT ERA for seabirds - objective 1 (Tuck et al 2011)	ICCAT	Longline	S	Breeding population status	N	Rapid decline (›2% per year)=3, decline=2, stable=1, increase=0	N/A
Pelagic seabirds	ICCAT ERA for seabirds - objective 1 (Tuck et al 2011)	ICCAT	Longline	S	Behavioural susceptibility to capture	Y	High=3, low=1. The last was based on the tendency of seabirds to follow fishing vessels and the relative incidence of bycatch in ICCAT or other fisheries.	N
Pelagic seabirds	Uruguay ERA for seabirds in longline fisheries	SW Atlantic	Longline	P	Demographic Invariant Method (DIM): use λmax (maximum annual growth rate)	N	Calculated with overall risk - no thresholds assigned	N/A
Pelagic seabirds	Uruguay ERA for seabirds in longline fisheries	SW Atlantic	Longline	S	Frequency of occurrence: number of counts in which a species occurred as a percent of the total number of counts of seabirds associated with the boats	N	Low (0.33): If population size is ›100,000 breeding pairs, FO‹25%; if population size is 10,000-100000 bp, FO‹10%, if pop size ‹10,000 bp, FO‹5% Medium (0.67): pop size large, FO 25-50%; pop size medium FO 10-25%, pop size small FO 5-10% High (1.00): large FO ›50%, medium FO ›25%, small FO ›10%	N/A
Pelagic seabirds	Uruguay ERA for seabirds in longline fisheries	SW Atlantic	Longline	S	Access to bait	Maybe	N of bait access/ N of bird present during observations: High ›67%ile, Medium 33‹x‹67%ile, Low ‹33%ile	Y but see attribute
Pelagic seabirds	Uruguay ERA for seabirds in longline fisheries	SW Atlantic	Longline	S	Hook selectivity	Maybe	High: Culmen›Total length (TL) of hook, Medium: Front length of hook‹Culmen‹TL, Low: Culmen‹FL	N
Pelagic seabirds	Uruguay ERA for seabirds in longline fisheries	SW Atlantic	Longline	S	Post-capture mortality	Y	High: number of dead birds/number captured approx 1	N
Sea turtles	ICCAT ERA for turtles (Angel et al 2014)	ICCAT	Longline, purse seine	P	Number of breeding females (threshold diff for each species)	Y	Diff for each species. Number of breeding females per RMU (population), e.g. Dermochlelys coriacea. Low productivity (high risk): Very small ‹10 or Small (10-100); Medium productivity: Medium (100-500) or large (500-1000). High productivity: very large (›1000)	Y

Species group	Assessment (ref)	Geographical area	Gear(s)	P or S	Attribute	Attribute useful MSC (Y/N)	Threshold	Threshold useful MSC (Y/N)
				P	Population trend	N	Low p (high risk): declining/uncertain; medium: stable, high p: increasing	Y
				P	Age at maturity	Y	low p: >30 years, medium: 16-30 years, high p: <16 years	Y
				P	Hatching success	Y	low p: <50%, medium 50-75%, high >75%	Y
				P	Emergence success	Y	low p: <50%, medium 50-75%, high >75%	Y
				P	Mean clutch size	Y	Low p: <90 eggs, Medium: 90-120, High p: >120	Y
				P	Nests/female/season	Y	Low p: <4 nests, Medium: 4-6, High p: >6	Y
				P	Remigration interval	Y	Low p: >4 years, Medium: 4-2.6, High p: <2.6	Y
				S	Overlap with ICCAT region (no. of 2.5 degree squares covered by a RMU's distribution as a proportion of all squres (2000) in the ICCAT region)	Y	Low s (low risk): <50, Medium: 50-100, High >100	Maybe
				S	Confidence (no. of satellite tracks)	N	Low s: <5, Medium: 5-30, High: >30	N/A
				S	Bycatch mortality relative to breeding females (%)	Maybe	Low s: <30, Medium: 30-100, High s: >100	Maybe but see attribute
Sea turtles	ERA for sea turtles in IOTC region (Nel et al 2013)	IOTC	Longline, purse seine, gillnet	P	Population trend	N	Low p (high risk): declining/uncertain; medium: stable, high p: increasing	N/A
				P	RMU size/clades (no. of nesting females)	Y	Low p (high risk): very small & small; Medium: medium & large: High: very large	N
				P	Age at maturity	Y	low p: >30 years, medium: 16-30 years, high p: <16 years	Y
				P	Natural survivorship: Nest success (inferred from literature on land based threats if not stated explicitly)	Maybe	low p (high risk): <50%; medium: 50-75%; high >75%	Y but see attribute
				P	Natural survivorship: Hatching and Emergence success (% of nests producing eggs)	Y	low p (high risk): <50%; medium: 50-75%; high >75%	Y
				P	Number of eggs per female	Y	Low p: <90 eggs, Medium: 90-120, High p: >120	Y
				P	No of clutches per individual per season	Y	Low p: <4 nests, Medium: 4-6, High p: >6	Y
				P	Remigration interval	Y	Low p: >4 years, Medium: 4-2.6, High p: <2.6	Y
				S	Management Strategy / Recovery plan	N	Wallace et al 2011 threat score	N/A

Species group	Assessment (ref)	Geographical area	Gear(s)	P or S	Attribute	Attribute useful MSC (Y/N)	Threshold	Threshold useful MSC (Y/N)
				S	Spatial overlap RMU with IOTC region (based on number of 2.5x2.5 degree squares with presence of turtle)	Y	Low s (low risk): <30; Medium: 30-60, High>60 squares	Maybe
				S	Confidence estimate in distribution data (based on number of tracks)	N	Low s: 1, Medium: 2, High: 3	N/A
				S	Bycatch estimate relative to natural mortality	Maybe	Low risk, Medium risk, High risk. Natural mortality for adult turtles was 5-10%. Values were rated as low at 30% catch rate to total estimated adult female numbers, medium at 100% and high >100% of estimated adult female numbers (or RMU size). For hard-shelled turtles this translates roughly as low if <500 individuals are caught and high if >1500 individuals are caught.	Maybe but see attribute
Cetaceans	Risk-based approach for screening vulnerability of cetaceans to fisheries bycatch (Brown et al 2013)	NE Atlantic	Gillnet, demersal longline, pots, otter trawls, seines, pelagic trawls	P	Age at female sexual maturity	Y	High risk: >=11 years; Medium: 6-10 years; Low risk: <=5 years	Y
				P	Oldest reproducing female	Y	High risk >=61 years, Medium: 45-60 years; Low risk <=44 years	Y
				P	Calf survival (proportion)	N	High risk <=0.76, Medium: 0.77-0.89; low risk >=0.90	N/A
				P	Intercalving interval	Y	High risk >3.5 years, Medium: 2.6-3.5, Low <=2.5 years	Y
				S	Availability	Y	High: NE Atlantic distribution/subspecies/subpopulation. Medium: N Atlantic distribution/subspecies/subpopulation. Low: Atlantic distribution	Maybe
				S	Encounterability	Maybe	High: Total spatial or temporal overlap; Medium: Spatial and temporal overlap and less than half of habitat range unaffected; Low: Spatial and temporal overlap but more than half of habitat range unaffected.	Y but see attribute
				S	Selectivity	Y	High: high potential for capture; Medium: moderate potential for capture; Low: low potential for capture	Y
				S	Potential for lethal encounter	Y	High risk: interaction with gear likely to result in death; Medium: interaction with gear likely to result in injury; low: interaction with gear unlikely to result in injury or death	Y
Cetaceans	Harbour porpoise & minke whale risk assessment in Irish Sea (Brown et al 2015)	Irish Sea	Gillnet, longlines, pots	P	Age at female sexual maturity	Y	High risk: >=11 years; Medium: 6-10 years; Low risk: <=5 years	Y
				P	Oldest reproducing female	Y	High risk >=61 years, Medium: 45-60 years; Low risk <=44 years	Y
				P	Calf survival (proportion)	N	High risk <=0.76, Medium: 0.77-0.89; low risk >=0.90	Y but see attribute
				P	Intercalving interval	Y	High risk >3.5 years, Medium: 2.6-3.5, Low <=2.5 years	Y
				S	Availability	Y	High risk: >30% overlap between fishing activity & species distribution; Medium: 10-30% overlap; Low <10% overlap	Y
				S	Encounterability	Maybe	High risk: Overlaps with fishery year-round; Medium: overlaps with fishery beyond the assessment period but not year round; Low: overlap limited to the assessment period	Y but see attribute

Species group	Assessment (ref)	Geographical area	Gear(s)	P or S	Attribute	Attribute useful MSC (Y/N)	Threshold	Threshold useful MSC (Y/N)
				S	Selectivity	Y	High: high potential for capture; Medium: moderate potential for capture; Low: low potential for capture	Maybe
				S	Potential for lethal encounter	Y	High risk: interaction with gear likely to result in death; Medium: interaction with gear likely to result in injury; low: interaction with gear unlikely to result in injury or death	Y
Sea snakes	Risk assessment for sea snakes in Australia Northern Prawn fishery (Milton 2001)	Australia	Prawn trawl	P	Maximum weight	Y	Low p (high risk): Max weight >3546g, Medium: 1974-3546g, High: <1974 g	Maybe
				P	% of biomass removed	N	Low p (high risk): Species where the estimated proportion of the biomass removed was greater than a quarter; Medium: Species where estimated proportion of the biomass removed was between a sixth and a quarter; High: Species where the estimated proportion of the biomass removed was between a sixth and a quarter	N/A
				P	Length at maturity	Maybe	Low p (high risk): Mean length of the snakes caught is significantly less than the length at sexual maturity. Medium: Mean length of the catch is statistically similar to the length at sexual maturity. High: The mean length of the catch is significantly longer than the length at sexual maturity.	Maybe but see attribute
				P	Mortality index	N	L p (high risk): Species with relative mortality (Z) >1.35; medium: Z between 0.88 and 1.35; High: Z<0.88	N/A
				P	Annual fecundity	Y	Low p (high risk): Annual fecundity <5.3 eggs (clutch size); Medium: Fecundity 5.3-8.2; Fecundity >8.2	Maybe
				S	Preferred habitat	Maybe	Low s (high risk): Species that primarily occur on soft or muddy sediments or prawn trawl grounds; Medium: Species that occur in soft sediment areas, but are known to migrate to coastal waters and use estuaries; High: Species that prefer habitats outside trawl areas ,such as reef habitat	Maybe
				S	Survival	Y	Low s (high risk): Species with the lowest survival rate from trawling (62-73%); Medium: 74-87%; High: 88-100%	Maybe
				S	Range	Y	Low s (high risk): Species that occurred in < 5 of 9 bioregions; Medium: 5-7 bioregions; High: >7 bioregions	Maybe
				S	Day/night	N	Low s (high risk): Species with higher catch rates in prawn trawls at night; Medium: Similar catch rates day and night: high: species with higher catch rates during the day	N/A
				S	Diet	Maybe	Low s (high risk): Species that eat benthic fish species that are regularly discarded from trawls; Medium: ate benthic species that did not regularly appear in prawn trawl catches; High: species eat only reef-associated species	N
Multi: sea turtles + fish	PSA Bycatch of Atlantic tuna: EU Tropical Purse seine & US pelagic longline fisheries	ICCAT	Longline, purse seine	P1	Productivity methodology 1= (RS)/3+(Lmat/Lmax) where RS= reproductive strategy. Lmat is length at maturity. Lmax is maximum length.	N	Calculated with overall risk - no thresholds assigned	N/A

Species group	Assessment (ref)	Geographical area	Gear(s)	P or S	Attribute	Attribute useful MSC (Y/N)	Threshold	Threshold useful MSC (Y/N)
	(Arrizabalaga et al 2011)			P2	Productivity methodology 2=Lmat/Lmax where Lmat is length at maturity and L max is maximum length.	N	Calculated with overall risk - no thresholds assigned	N/A
				S1	Susceptibility methodology 1= (Lcatch/Lmax +Pdead)/2. where Lcatch is average length of catch for each species. Pdead is proportion of dead animals after interacting with fishing gear.	N	Calculated with overall risk - no thresholds assigned	N/A
				S2	S2=Pdead where Pdead is proportion of dead animals after interacting with the fishing gear	N	Calculated with overall risk - no thresholds assigned	N/A
Multi: Cetaceans, pelagic seabirds, sea turtles + fish	WCPO tuna ERA (Kirby 2006)	WCPFC	Longline, purse seine	P	Composite P index: (Reproductive strategy/3)+(Length at maturity/maximum length)	N	Calculated with overall risk - no thresholds assigned	N/A
				S1	Composite S index 1: (1/3)x ((Length at capture/maximum length)+ condition at capture proportion retained))	N	Calculated with overall risk - no thresholds assigned	N/A
				S2	Composite S index 2: (1/3)x ((Length at capture/length at maturity)+ condition at capture proportion retained))	N	Calculated with overall risk - no thresholds assigned	N/A
Multi: sea turtles + fish	Initial risk assessment for IOTC (Murua et al 2009)	IOTC	Longline	P	Composite P index: (Reproductive strategy/3)+(Length at maturity/maximum length)	N	Calculated with overall risk - no thresholds assigned	N/A
				S	Composite S index: (Length at capture/maximum length +proportion dead)/2	N	Calculated with overall risk - no thresholds assigned	N/A
Multi: Cetaceans, Sirenians, Sea turtles, Elasmobranchs	SWIOFP ERA artisanal fisheries (Kiszka 2012)	Kenya, Tanzania, Mozambique and Mauritius	Drift gillnets, bottom set gillnets, beach seines and handlines	P	Age at maturity	Y	Unknown (not reported)	N/A
				P	Size at maturity	Y	Unknown (not reported)	N/A
				P	Maximum age	Y	Unknown (not reported)	N/A
				P	Fecundity	Y	Unknown (not reported)	N/A
				P	Reproductive strategy	Y	Unknown (not reported)	N/A
				P	Range (global and regional distributions)	N	Unknown (not reported)	N/A

Species group	Assessment (ref)	Geographical area	Gear(s)	P or S	Attribute	Attribute useful MSC (Y/N)	Threshold	Threshold useful MSC (Y/N)
				P	Global population size	N	Unknown (not reported)	N/A
				P	Habitat characteristics	N	Unknown (not reported)	N/A
				P	Diet	N	Unknown (not reported)	N/A
				S	Mean regional bycatch incidence: mean of bycatch incidence (N individuals/taxonomical group) in past year for each surveyed country	N	Unknown (not reported)	N/A
				S	Commercial value	N	Unknown (not reported)	N/A
				S	Gear selectivity	Y	Unknown (not reported)	N/A
				S	Habitat overlap between gear and bycatch species	Maybe	Unknown (not reported)	N/A
				S	Post-capture survival	Y	Unknown (not reported)	N/A
Multi: Pinnipeds, cetaceans + fish	Cumulative risk assessment for multiple fisheries (Micheli et al 2014)	Baja California, Mexico	Small scale drift nets, set nets, fish traps, lobster traps, divers	P	Average age at maturity	Y	Low p (high risk): >4 years, Medium: 2-4 years, Low <2 years	N
				P	Average maximum age	Y	Low p (high risk): >40 years, Medium: 20-40 years, Low <20 years	N
				P	Fecundity	Y	Low p (high risk): < 100 eggs per year, Medium: 100-10,000 eggs per year; High: >10,000 eggs per year	N
				P	Average maximum size	Y	Low p (high risk): >80cm, Medium: 40-80cm, High <40 cm	N
				P	Average size a maturity	Y	Low p (high risk): >100 cm, Medium: 40-100 cm; Low <40 cm	N
				P	Reproductive strategy	Y	Low p (high risk): Live bearer; medium: Demersal egg layer; High: Broadcast spawners	N
				P	Trophic level	Maybe	Low p (>3.5; Medium: 2.5-3.5; Low <2.5	N
				S	Availability	Y	Low s (low risk): Global, Medium: Pacific coast (N & S America), Low: Baja/Mexico only	Maybe
				S	Encounterability - habitat	Maybe	Low s (low risk): Low overlap with fishing gear; Medium: Medium overlap with fishing gear, High: High overlap with fishing gear	Maybe
				S	Encounterability - bathymetry	Maybe	Low s (low risk): Low overlap with fishing gear; Medium: Medium overlap with fishing gear, High: High overlap with fishing gear	Maybe
				S	Selectivity - nets	Maybe	Low s (low risk): <17.8cm average size at maturity; Medium: 17.8-35.6cm; High >35.6cm	N
				S	Selectivity - fish traps	Maybe	Low s (low risk): <18cm average size at maturity; Medium: <3cm; High >3-18cm	N
				S	Selectivity - lobster traps	Maybe	Low s (low risk): <19.6cm average size at maturity; Medium: <8.9cm; High >8.9-19.6cm	N
				S	Selectivity - dive fishing	Maybe	Low s (low risk): Non-target species, Medium: not applicable; High: Target species	N
				S	Post-capture mortality	Y	Low s (low risk): Evidence of post-capture release and survival; Medium: Released alive; High: Retained species or majority dead when released	Y
		Australia	Longline	P	Average age at maturity	Y	Low p (high risk): >15 years, Medium: 5-15 years, High: <5 years	Maybe

Species group	Assessment (ref)	Geographical area	Gear(s)	P or S	Attribute	Attribute useful MSC (Y/N)	Threshold	Threshold useful MSC (Y/N)
Multi: Cetaceans, pinnipeds, pelagic seabirds, turtles, sea snakes + fish	ERAEF for the automatic longline sub-fishery of the Southern and Eastern Shark and Scalefish fishery* (Daly et al 2007)			P	Average maximum age	Y	Low p (high risk): >25 years, Medium: 10-25, High: <10 years	Maybe
				P	Fecundity	Y	Low p (high risk): <100 eggs per year; Medium: 100-20,000 eggs per years; High >20,000 eggs per year	Maybe
				P	Average maximum size	Maybe	Low p (high risk): >300cm, Medium: 100-300 cm; High: < 100 cm	Maybe but see attribute
				P	Average size at maturity	Maybe	Low p (high risk): >200 cm, Medium: 40-200 cm, High <40 cm	Maybe but see attribute
				P	Reproductive strategy	Maybe	Low p (high risk): Live bearer (and birds); Medium: Demersal egg layer; High: Broadcast spawners	Maybe but see attribute
				P	Trophic level	Maybe	Low p (high risk): >3.25, Medium: 2.75-3.25, High <2.75	Maybe but see attribute
				S	Areal overlap	Y	2 options: where good distribution maps available=distributional range in Australia (km2)/fraction of the species distribution where effort occurs. Low s (low risk): <10% overlap, medium: 10-30% overlap, high>30% overlap. Where good distribution maps not available, low s(low risk): Globally distributed; medium: Southern Hemisphere; high: Australian endemic	Maybe

Species group	Assessment (ref)	Geographical area	Gear(s)	P or S	Attribute	Attribute useful MSC (Y/N)	Threshold	Threshold useful MSC (Y/N)
				S	Encounterability (habitat and bathymetry)	Y	Low/medium/high overlap with fishing gear. For habitat overlap: Species are divided into benthic (bottom) species, water column (pelagic) species and air column species (birds, mammals, reptiles). Benthic species are further divided into hard bottom (e.g. rock/reef) species and soft bottom (e.g. sand/mud) species. Species that occur in the water column are further divided into benthopelagic (bottom third of the water column) mesopelagic (middle third of the water column) and epipelagic (upper third of the water column). Species that occur in poorly known parts of the deep ocean (700–3,000 m), where the water column is poorly defined, may be scored bathypelagic. Some species occur in more than one habitat and a number of habitat codes will be assigned. For these species, the risk score is initially set for the worst case code. The bathymetry check is used to check the encounterability risk score for false positives. A species may be vulnerable to a particular gear type due to a common position within the water column or on a common bottom type–high potential risk. However if the species occurs outside the bathymetric range of a fishery the actual risk is low. Habitat for marine birds, reptiles and mammals is epipelagic/air. All species are potentially encountered during deployment and retrieval of either demersal or pelagic gear. These species are vulnerable to drowning before capture. The default encounterability score for these groups is high. Actual encounterability for birds depends, in part, on mitigation measures which may or may not be effective. In fisheries that have observer programs, encounterability scores may be reduced. For example, if an observer sees pilot whales every day he/she observes auto-longline fishing but the pilot whales never approach the gear or take fish off the hooks, then availability is high but encounterability is over-ridden to low.	Y
				S	Selectivity	Y	Scores vary by gear type - body size in relation to gear size. For hooks defined by typical weights of the species caught relative to the breaking strain of the snod and gaffing method used in the fishery	Maybe
				S	PCM	Y	Low s (low risk): Evidence of post-capture release and survival; Medium: Released alive; High: Retained species or majority dead when released	Y

*multiple ERAEF assessments but selected this as all attributes and thresholds are the same.