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Evaluating the appropriateness of risk-based approaches to assess the sustainability of fishery impacts on seabirds

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ABSTRACT: Many seabird populations are declining, with fisheries bycatch as one of the greatest threats. Explicit risk criteria should be used to identify whether bycatch is a problem for particular species and fisheries, but these are often poorly defined. A variety of methods are used to determine the risk that a specific fishery is having an unsustainable impact on a seabird population. Up until October 2022, the Marine Stewardship Council (MSC) applied a general semi-quantitative productivity susceptibility analysis (PSA), a tool that has also been used widely by other management agencies for diverse taxa. Given the need to ensure fisheries risk assessments are robust and consistent, we examined how general PSAs perform when applied in 2 situations with good information on both the seabird population and fisheries bycatch rates and compare the outputs with those from 2 accessible and more quantitative tools: potential biological removal and population viability analysis. We found that risk scoring using the previous MSC version of the PSA was less robust and precautionary than using other approaches, given the steep declines observed in some seabird breeding populations. We make recommendations on how to select attributes for species-specific PSAs and, depending on the data available, identify the most appropriate risk assessment method to achieve a given objective. These should help ensure more consistent assessment and prioritisation of seabird bycatch issues, and improved ecosystem-based management of fisheries.

KEY WORDS: Bycatch · Seabirds · Risk assessment · Fisheries impacts · Productivity susceptibility analysis

1. INTRODUCTION

Nearly a third of the world's seabirds are threatened, and almost half show declining population trends (Dias et al. 2019). One of the greatest threats is fisheries bycatch, especially for large petrels and albatrosses (Croxall et al. 2012, Phillips et al. 2016). Identifying fisheries with unsustainable bycatch is essential for effective conservation and ecosystem-based approaches to fisheries management (FAO 2003, Phillips et al. 2016). Explicit risk criteria are required to determine whether seabird bycatch is likely to have a negative impact on particular species/populations, and to monitor bycatch mitigation (Small et al. 2013, Good et al. 2020). Possible approaches to risk assessment include indices of spatial overlap of seabirds and fisheries (e.g. Le Bot et al. 2018, Clay et al. 2019, Zhou & Brothers 2021), semi-quantitative productivity susceptibility analysis (PSA) (e.g. Tuck et al. 2011, Jiménez et al. 2012, Waugh et al. 2012), potential biological removal (PBR) (e.g. Dillingham & Fletcher 2008, 2011) and model-based approaches to

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assess fisheries impact on population growth rates, such as population viability analysis (PVA) (e.g. Tuck et al. 2001, 2011, Wiese & Smith 2003, Baker & Wise 2005, Finkelstein et al. 2010, Pardo et al. 2017). Model-based methods require accurate information on demographic parameters and fishing mortalities, so when these data are unavailable, precautionary methods to estimate risk should be used (Small et al. 2013).

PSA is a semi-quantitative risk assessment that was developed for assessing relative risk to bycatch species in Australian fisheries (Hobday et al. 2007, Smith et al. 2007), but has now been used for over 1000 target and bycatch species globally (Hordyk & Carruthers 2018). It was also adapted by the Marine Stewardship Council (MSC), which is an international body that operates a seafood ecolabelling and certification programme to evaluate whether the impact of a candidate fishery is sustainable in data-limited situations (MSC 2018). The PSA used by the MSC before the latest Fisheries Standard Review (hereafter MSC PSA v2.0) was designed for use across a range of taxa, i.e. it was general, rather than specific to species groups such as seabirds. Although the MSC have a new PSA (v3.0), the MSC PSA v2.0 will continue to be used until 1 May 2023 for any new fisheries that are being assessed, and until at least 1 November 2025 for fisheries that are already certified (MSC 2023). The MSC PSA v2.0 may also still be used in other fisheries, including those in projects aimed to support future certification.

In general, the PSA is a precautionary tool and should incorporate values for each attribute that are appropriate to the species and fishery of interest (Hobday et al. 2011). It requires information on productivity, behaviour and distribution of the bycatch species, as well as the type of gear, area of operation and deployment method used in the fishery (MSC 2018).

Few studies have tested the assumptions underpinning PSA in general (see Hordyk & Carruthers 2018), and to date, none specifically on its application to fisheries impacts on seabirds. The objective of our study was to determine the appropriateness of the MSC PSA v2.0 methodology for assessing the sustainability of individual fisheries that are seeking certification on seabird populations. The results are also relevant for other marine species with similar life-history characteristics. We applied the MSC PSA v2.0 in 2 case studies, focusing on 2 seabird populations of global importance for which there is good information on demographic parameters, as well as on bycatch rates in specific fisheries in one or more years: (1) wandering albatross *Diomedea exulans* bycatch in southwest Atlantic tuna fisheries in ca. 2005–2010 and (2) black-browed albatross *Thalassarche melanophris* bycatch in South African trawl fisheries for hake (*Merluccius* spp.) in 2004. We compared results from PSA to those using 2 other methods, which may not be the most complex population modelling tools available but are relatively simple to apply by non-seabird experts: PBR and PVA. The appropriateness of the MSC PSA v2.0 is discussed along with that of the other 2 methodologies to establish best practice when estimating risk of fishery impacts on seabirds. We make several recommendations that apply to seabird–fisheries risk assessment by the MSC and other national and international fisheries management bodies.

2. MATERIALS AND METHODS

2.1. Case study parameters

2.1.1. Wandering albatross, southwest Atlantic pelagic longline fishery, 2005–2010

Wandering albatrosses on South Georgia have been monitored continuously for more than 40 yr and represent ~18% of the global population (Phillips et al. 2016, Pardo et al. 2017, Poncet et al. 2017). The species is categorised as globally Vulnerable on the IUCN Red List, and the South Georgia birds are designated a Priority Population for conservation by the Agreement on Conservation of Albatrosses and Petrels because of the steep decline and global importance (ACAP 2012). Given its wide breeding and nonbreeding ranges, this population overlaps with a wide range of national and international fisheries (Clay et al. 2019). This includes the Uruguayan, Brazilian and Japanese pelagic longline fleets in the southwest Atlantic, on which observers have recorded bycaught wandering albatrosses in particularly high numbers relative to the population size (Bugoni et al. 2008, Jiménez et al. 2010, 2014). Tracking of breeding and nonbreeding adults from multiple populations, along with ring recoveries in fisheries, indicate that the majority or all of these birds are from South Georgia (Jiménez et al. 2012, Clay et al. 2019, Carneiro et al. 2020).

2.1.2. Black-browed albatross, South African hake trawl fishery, 2004

The South Georgia population of black-browed albatrosses has also been studied for over 40 yr and represents ~12 % of the global population (Phillips et al. 2016, Pardo et al. 2017, Poncet et al. 2017). Although this species is listed as Least Concern globally by the IUCN, ACAP consider the black-browed albatrosses at South Georgia to be a Priority Population for conservation, because of the steep decline and global importance (ACAP 2012). Birds in this population were bycaught in large numbers in the local South Georgia longline fishery for Patagonian toothfish *Dissostichus elegenoides* until the introduction of mitigation measures. These included a closed summer season, night setting, use of streamer lines and heavier line weighting, and reduced bycatch to negligible levels in the early 2000s (Collins et al. 2021). Black-browed albatrosses are also killed in interactions with trawlers and longliners in the Benguela Current during non-breeding periods, when juveniles are also at risk (Croxall et al. 1998, Petersen et al. 2008, Clay et al. 2019). Particularly high mortality rates were recorded on South African hake trawlers in 2004, although these have since been reduced considerably by mitigation measures (Watkins et al. 2008, Maree et al. 2014). Tracking indicates that most black-browed albatrosses in the Benguela are likely from South Georgia (Clay et al. 2019, Carneiro et al 2020). Although the small population at Kerguelen also uses the Benguela Upwelling, this represents just ~0.5 % of global numbers (Phillips et al. 2016), and for the purposes of this analysis, we assume all bycaught individuals are from South Georgia.

2.2. PSA

In a PSA, risk is assessed according to productivity and susceptibility attributes (Hobday et al. 2007). The MSC PSA v2.0 productivity attributes include age at maturity, maximum age, fecundity, average maximum size, average size at maturity, reproductive strategy and trophic level (MSC 2018). The susceptibility attributes include areal overlap, encounterability, selectivity and post-capture mortality (MSC 2018). Each attribute has 3 risk categories: low risk (=1), medium risk (=2) and high risk (=3) based on thresholds derived from the characteristics of 600 species in Australian commonwealth waters (Hobday et al. 2011) (for the MSC PSA v2.0 attributes and thresholds, see Tables S1–S3 in Supplement 1 at www.int-res.com/articles/suppl/n051p161_supp.pdf; for all supplements). In the MSC PSA v2.0, each attribute is scored according to the thresholds, and a productivity score is calculated as the arithmetic mean of the individual productivity attribute scores. The susceptibility attribute scores are multiplied and rescaled to the interval [1–3] to provide an overall susceptibility score. The productivity and susceptibility scores are then plotted on the PSA diagnostic plot. A single risk score is calculated as the Euclidean distance from the nominal origin (0.5, 0.7), calculated as $R = \sqrt{(P^2 + S^2)}$, where R is the risk score, P is the productivity score, and S is the susceptibility score (MSC 2018).

To evaluate whether the MSC PSA v2.0 is robust and precautionary, we applied it to 8 different scenarios in each case study. In the default scenario, we applied best-available information for productivity attributes and the best biological interpretation of susceptibility attributes. Values for each attribute were taken from the literature or unpublished datasets. In the other scenarios, we replicated use of inaccurate or imprecise data for the productivity risks. For the inaccurate data, we reduced the best available value by 1 SD, and for the imprecise data, we took the lower 95 % CI of the best available information. For the combined inaccurate and imprecise data, we reduced the best available data by 1 SD and then took the lower 95 % CI. For the susceptibility attributes, we applied either a biological or literal interpretation of the requirement. Values for each of the scenarios are provided in Tables S4 & S5 in Supplement 2.

In the MSC PSA methodology, 2 productivity attributes for seabirds receive the same score: fecundity and trophic level, which both score a high risk (3). For most of the other productivity attributes, we varied the accuracy and precision of available data on the attribute or a proxy. The categories used for the attribute indicating reproductive strategy are not numeric. In this case, we used the best biological interpretation for the default scenario and a literal interpretation for the inaccurate scenarios; it was not possible to vary precision.

For the susceptibility attributes, the approach we applied for the default scenario was to take the best available biological information on the species relative to the intent of the attribute, e.g. using information on species behaviour and distribution. In the worst-case scenario, we used only the literal interpretation of the requirements as specified without applying specific knowledge on the species. The overall risk score was calculated when the scores for each productivity and susceptibility attribute were input into the MSC PSA Worksheet (MSC 2018). In this worksheet, the risk score is converted into a category: low, medium or high, and a resulting MSC

Performance Indicator score and category are provided (Pass, Pass with condition, Fail). The risk scores and resulting categories were calculated for 8 scenarios: the 4 productivity scenarios combined with the 2 susceptibility scenarios.

2.3. Comparison of outputs from PSA with PBR and PVA

Although the types of outputs differ between the PSA, PBR and PVA, we tested the assumption that the PSA results are more precautionary, i.e. if the resulting risk categories from the PSA would be at least the same level or higher than those from the other methods.

2.3.1. PBR

PBR estimates the number of animals that can be removed from a population by all anthropogenic processes while still allowing maximum net productivity (Wade 1998). This method was designed for cetaceans but is also applicable to seabirds (e.g. Žydelis et al. 2009, Richard & Abraham 2013). We used a specific PBR method developed for albatrosses and petrels, according to the following equation (Dillingham & Fletcher 2011):

$$\mathrm{PBR} = \tau f B \tag{1}$$

where τ is the maximum growth rate (without anthropogenic mortalities) and a species-appropriate population multiplier that incorporates uncertainty in the estimate of the number of breeding pairs; f is a recovery factor included in the equation to hasten recovery of depleted populations and to account for additional uncertainties in the metrics, set at a value between 0.1 and 1, depending on the conservation status of a species or management objectives, and B is the estimated number of breeding pairs.

To create the 6 scenarios for testing, we applied 2 different recovery factors following Wade (1998) for species that are threatened (0.1) and other species (0.5), and 3 bycatch estimates. For the wandering albatross, the bycatch estimates were 150 birds yr^{-1} (ICCAT 2009), and 88 and 256 birds yr^{-1}. We estimated the latter based on the total number of wandering albatrosses (at least 9 and 11) bycaught by the Uruguayan fleet in 2005–2006, scaled by the proportion of effort from this fishery relative to other pelagic longline effort in the southwest Atlantic in those years (Jiménez et al. 2012). For the black-browed albatross, the mean and lower and upper 95% CI from Watkins et al. (2008) were used as the bycatch values (5000, 2500 and 8500 birds yr^{-1}, respectively). We used values from Watkins et al. (2008) rather than the updated estimates of Maree et al. (2014), as the former were the estimates available to fisheries managers at the time of the case study and were more precautionary. Where the PBR value exceeded the bycatch estimate, we assigned a risk category of 'high;' otherwise, we assigned a risk category of 'low.'

2.3.2. PVA

PVA allows the user to examine implications of different harvest levels on population growth rate and probability of reaching a user-defined extinction or 'quasi-extinction' threshold (Lacy & Pollak 2014). We used the accessible PVA tool VORTEX v10 (Lacy & Pollak 2014) for our study. VORTEX has been applied to assess anthropogenic impacts on seabirds (e.g. Hamilton & Moller 1995, Majluf et al. 2002, Baker 2016) by simulating the effects of deterministic forces as well as stochastic events using Monte Carlo methods (Lacy et al. 2018).

We obtained demographic information to populate the models from the literature (Supplement 2) using breeding success and age-based survival from periods prior to industrial fishery impacts, or before large population declines. These 'optimal' values were used because direct estimates of survival from the 2 study populations are only available since the advent of industrial fisheries and so already include fisheries-related mortality. We undertook sensitivity tests to consider uncertainty in key demographic characteristics of the South Georgia wandering albatross population. The 4 key demographic parameters, namely percentage of females breeding (including probability of return and probability of laying), breeding failure, juvenile mortality (2–6 yr) and adult mortality (>6 yr), were compared to see which had most influence on exponential growth rate (λ) by changing parameter values by 10%.

For our analysis, the default scenario also included 10% SD in each demographic parameter due to environmental variation (based on Pardo et al. 2017) for our sensitivity tests. We used the same bycatch mortality values as in the PBR case study (3 for each species) and applied them using the 'Harvest' function in VORTEX to 3 different age-specific bycatch scenarios for each species.

For wandering albatross, the age-specific bycatch scenarios were: 80% adult, 50% female (reflecting assumed population structure), 80% adult, 77% female (Gianuca et al. 2017) and 53% adult, 77% female (Gianuca et al. 2017). When combined with the bycatch values, we evaluated a total of 9 scenarios. For black-browed albatross, the age-specific bycatch scenarios were: 80% adult, 50% female (based on assumed population structure), and 39% adults, 59% females (based on data in Petersen et al. 2009 for longline fisheries, assuming spatial overlap of both fisheries with the species is the same). When combined with the bycatch total, there were 6 scenarios to evaluate. Each scenario was run with 1000 iterations over a period of 3 generations, and resulting annual growth rates (λ) were recorded. Where the default annual growth rate changed from positive (no bycatch scenario) to negative, we assigned a risk category of 'high;' otherwise, we assigned a risk category of 'low.'

Table 1. Productivity scores of wandering albatross for each attribute, and overall productivity score when applying different information quality. Grey shading indicates where there are changes from the default value for overall risk score. 1 = low risk, 2 = medium risk, 3 = high risk

Attribute	Best available	Inaccurate	Imprecise	Inaccurate & imprecise
Average age at maturity	2	2	2	2
Average maximum age	3	3	3	3
Fecundity	3	3	3	3
Average maximum size	2	2	2	1
Average size at maturity	2	2	2	2
Reproductive strategy	3	2	3	2
Trophic level	3	3	3	3
Overall productivity score	**2.57**	**2.43**	**2.57**	**2.29**

Table 2. Susceptibility scores of wandering albatross for each attribute and overall productivity score when applying different interpretations. Grey shading indicates where there are changes from the default value for overall risk score. 1 = low risk, 2 = medium risk, 3 = high risk

Attribute	Biological interpretation	Literal interpretation
Areal overlap	2	1
Encounterability	3	1
Selectivity	2	1
Post-capture mortality	3	2
Overall susceptibility score	**1.88**	**1.03**

3. RESULTS

3.1. Wandering albatross case study

The PSA productivity scores were largely consistent across scenarios. Risk categories only changed (e.g. from medium to low) across scenarios for 2 attributes (Table 1). The attribute for average maximum size changed from medium (2) to low (1) when inaccurate and imprecise information was used. The attribute on reproductive strategy changed from high risk (3) to medium risk (2) when inaccurate, or inaccurate and imprecise information was used. The overall productivity score did not change when only imprecise information was used, but was lower if inaccurate, or inaccurate and imprecise, information was used (Table 1).

The PSA susceptibility scores differed for each attribute; the literal interpretation led to a lower risk score in each case (Table 2). This was also reflected in the overall susceptibility score.

The resulting PSA analyses for the different scenarios were less precautionary in outcome when compared to the results from PBR and PVA (Fig. 1). The PSA scores for 6 of 8 scenarios indicated that there would be a medium risk of the fishery hindering recovery of this population. In an MSC context, this fish-

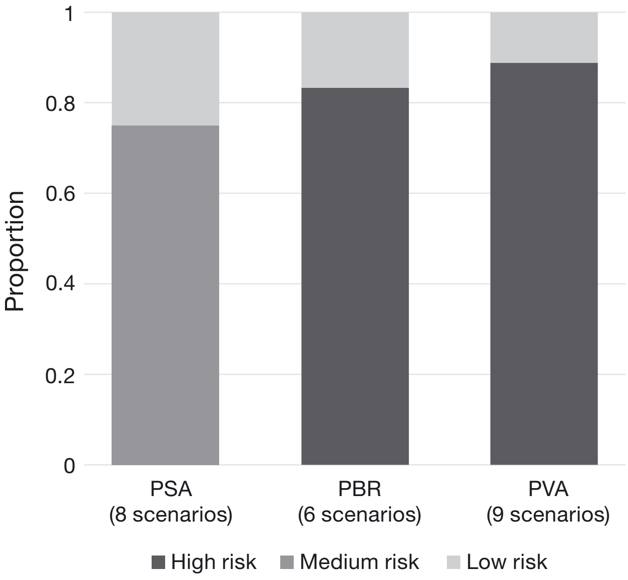

Fig. 1. Comparison of assigned risk categories from the application of productivity susceptibility analysis (PSA), potential biological removal (PBR) and population viability analysis (PVA) to the wandering albatross population at South Georgia using different scenarios

ery would pass certification with a requirement to make improvements over 5 yr. PSA scores for the 2 scenarios with inaccurate inputs for productivity, and literal interpretations for susceptibility resulted in an overall low risk score for the PSA (see Tables S6–S11 in Supplement 3). In these cases, a fishery would receive a passing score for this Performance Indicator without the need to make improvements.

In contrast to the PSA results, 5 of the 6 PBR scenarios were determined to be high risk (Fig. 1; Supplement 3). The sensitivity tests run in VORTEX for wandering albatross showed that adult mortality and percent females breeding were the most influential parameters in the model, but even when these were varied, the model outputs indicated similar mean exponential growth rates (λ) and associated low CV (see Table S12 in Supplement 4). The results of the PVA for wandering albatross were similar to those of the PBR in that 8 of 9 scenarios were determined to be high risk (Fig. 1; Supplement 3).

Table 3. Productivity scores of black-browed albatross for each attribute and overall productivity score when applying different information quality. Grey shading indicates where there are changes from the default in overall risk score. 1 = low risk, 2 = medium risk, 3 = high risk

Attribute	Best available	Inaccurate	Imprecise	Inaccurate & imprecise
Average age at maturity	2	2	2	2
Average maximum age	3	3	3	3
Fecundity	3	3	3	3
Average maximum size	1	1	1	1
Average size at maturity	2	2	2	2
Reproductive strategy	3	2	3	2
Trophic level	3	3	3	3
Overall productivity score	**2.43**	**2.29**	**2.43**	**2.29**

Table 4. Susceptibility scores of black-browed albatross for each attribute and overall productivity score when applying different interpretations. Grey shading indicates where there are changes from the default in overall risk score. 1 = low risk, 2 = medium risk, 3 = high risk

Attribute	Biological interpretation	Literal interpretation
Areal overlap	3	1
Encounterability	3	1
Selectivity	2	1
Post-capture mortality	2	1
Overall susceptibility score	**1.88**	**1.00**

3.2. Black-browed albatross

The overall productivity scores were similar to those for the wandering albatross, and largely consistent (Table 3). Only the attribute indicating reproductive strategy changed from high risk (3) to medium risk (2) when there was a literal interpretation based on inaccurate only and on combined inaccurate and imprecise information.

The scores for the susceptibility attributes were similar between the wandering albatross and black-browed albatross case studies, even though the 2 populations interact with different fisheries and gears. For the black-browed albatross study, the literal interpretation of the susceptibility attributes resulted in a lower risk score in each case (Table 4). This was also reflected in the overall susceptibility score.

The overall PSA scores were medium risk in 4 scenarios and low risk in 4 scenarios (Supplement 3). The results from the PSA for the black-browed albatross were less precautionary than using PBR (5 were high risk and 1 was low risk), but broadly consistent with the results from PVA (3 were high risk and 3 were low risk) (Fig. 2). The PSA resulted in low risk scores when the lowest estimate for bycatch was used, or the proportion of adult birds was only 39% (Supplement 3).

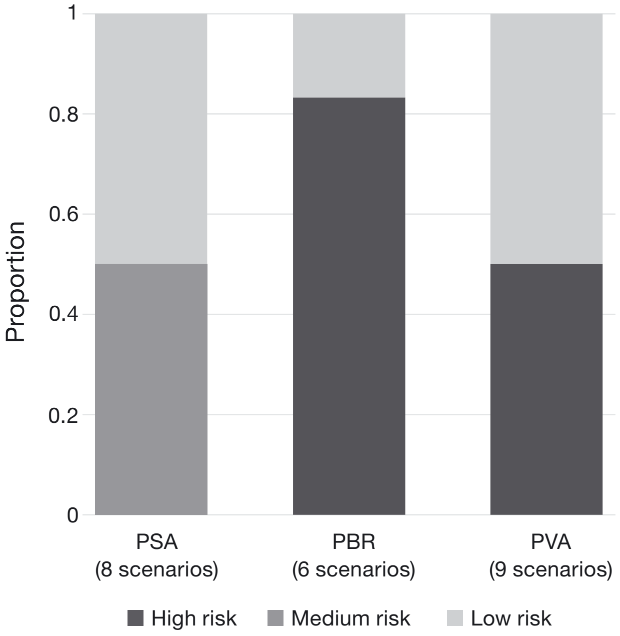

Fig. 2. As in Fig. 1, but for the black-browed albatross population at South Georgia

4. DISCUSSION

4.1. Application of PSA in seabird–fisheries risk assessments

Our results show that the MSC PSA v2.0 is not appropriate for assessing fishery impacts on seabirds because (1) productivity attributes do not adequately reflect the extreme life-history characteristics of seabirds; (2) productivity thresholds do not allow a sufficient level of discrimination among seabird species; and (3) the literal explanations for susceptibility attributes are inadequate. In addition, the quantification of risk within the PSA could be questioned as the thresholds are defined numerically but do not represent actual values (e.g. how much better is a risk score of 1 than a risk score of 2); this can be problematic when the numbers are combined rather than interpreted relative to each other (Game et al. 2013).

We recommend that PSAs as applied to seabirds focus on a smaller number of appropriate attributes to reduce prediction error rate (Hordyk & Carruthers 2018). The attribute indicating trophic level should be removed, as trophic level can vary between populations of the same seabird species, and data are often missing that would allow this attribute to be scored reliably (Shealer 2002, Gagné et al. 2018). Indeed, our study showed that the trophic level attribute was not useful for distinguishing between wandering and black-browed albatrosses, even though $\delta^{15}N$ values indicate that wandering albatrosses feed at approximately 1 trophic level higher than black-browed albatrosses in both the breeding and nonbreeding seasons (Phillips et al. 2009, 2011). Removing this attribute is consistent with PSA approaches designed specifically for seabirds, cetaceans and sea turtles (Tuck et al. 2011, Jiménez et al. 2012, Waugh et al. 2012, Brown et al. 2013, 2015, Nel et al. 2013, Angel et al. 2014).

Changes in size (body mass) with age in seabirds are of much lower magnitude than the differences in size among most species (Weimerskirch 2002). Further, size-related attributes are redundant if age-related attributes are already incorporated in the PSA. Even more importantly, there is no correspondence between relative body length and productivity in seabirds. For example, the spotted shag *Phalacrocorax punctatus* is 64–74 cm long and has an estimated maximum population growth rate (r_{max}) of 0.233, whereas the white-chinned petrel *Procellaria aequinoctialis* is only 50–58 cm long but has an r_{max} of 0.076 (Carboneras et al. 2020, Orta et al. 2020, Richard et al. 2020) — this is the opposite of the PSA assumption, i.e. that larger-sized species have lower population growth rates. We therefore recommend removing the size-specific attributes, as in the taxon-specific PSAs listed above.

We recommend using a suite of attributes that are more appropriate for seabirds, marine mammals and turtles, including life-history strategy (incorporating number of eggs and frequency of breeding), which was selected as the sole productivity attribute in the International Commission for the Conservation of Atlantic Tunas (ICCAT) seabird risk assessment (Tuck et al. 2011, Small et al. 2013). A method using maximum population growth rate was used in the Uruguayan seabird risk assessment, but this approach is more quantitative, and requires reliable data on adult survival and age at first breeding which may be unavailable, particularly for burrow or crevice-nesting seabirds that are more difficult to monitor (Jiménez et al. 2012, Small et al. 2013). The Western and Central Pacific (WCPFC) seabird risk assessment compared the use of maximum population growth rate with a fecundity factors index, which included life-history strategy and age at first breeding, and found them to be highly correlated, so these attributes were used in concert if maximum population growth rate was not known (Waugh et al. 2012). Missing demographic parameters could also be reconstructed using hierarchical frameworks to estimate population growth rates for risk assessments, e.g. as applied by Horswill et al. (2021).

Based on our case studies, the scores of most productivity attributes did not differ when less accurate and less precise demographic information was used, indicating that the thresholds used for productivity attributes in the MSC PSA v2.0 are too broad to distinguish between different seabird life histories. Some of the productivity attribute scores would be the same for both albatrosses as for seabirds with less extreme life-history characteristics, e.g. fecundity, reproductive strategy and trophic level. It is important in risk assessments that thresholds capture differences between species, for example to evaluate relative risks to pelagic and coastal seabirds where pelagic seabirds tend to have poorer conservation status likely due to their demographic characteristics, small population sizes and the restricted number and range of breeding sites (Croxall et al. 2012, Dias et al. 2019).

Susceptibility attributes have a greater influence than productivity attributes on overall scores in PSAs (Hordyk & Carruthers 2018). Therefore, ensuring that the interpretation of susceptibility attributes is appropriate for the evaluated species is vital when it comes to assessing risk of fishery impact on seabirds. The MSC PSA v2.0 attribute on areal overlap does not specify how changes in distribution should be considered or the scale of overlap. Data quality can have a major influence on predicted distributions and habitat use of seabirds (Goetz et al. 2022). The review by Small et al. (2013) describes how information of varying quality on seabird distribution can be included in risk assessments. Our study demonstrated that the current encounterability attribute of the MSC PSA v2.0 does not adequately capture relative risk, as seabirds that interact with gear above the surface (i.e. striking trawl warps or taking bait on hooks at the surface during setting) will always receive a low risk score in the MSC PSA v2.0 if only vertical overlap is considered. Behavioural characteristics such as tendency to follow vessels or diving behaviour should be preferred, as in Tuck et al. (2011) for longlines or Sonntag et al. (2012) for gillnets. Our study also highlighted issues with the selectivity attribute in that the MSC PSA v2.0 focuses on potential for individuals to be captured that are smaller than the size at maturity, but for albatrosses the main driver or population growth rate is adult as opposed to juvenile mortality (Pardo et al. 2017). For seabirds, it is more relevant to focus on whether the gear affects bycatch rates or cryptic mortality; for example, for Uruguayan pelagic longlines, Jiménez et al. (2012) used morphological characteristics (length of culmen relative to hook size) to assess the likelihood of species being retained until recorded at hauling. Specific susceptibility criteria related to morphological or behavioural characteristics were also included in PSAs designed for cetaceans, where a risk-matrix approach was developed to provide default scores for selectivity (Brown et al. 2013).

Another approach for susceptibility was taken in the WCPFC risk assessment, which used normalised species distributions, either calculated from foraging radius and proportion of the species that was breeding each year, or tracking data, as well as fishing effort and a vulnerability factor that included observer data to score risk (Waugh et al. 2012). However, this level of information may not be available for all species. As Small et al. (2013) indicated, there is a need to strike a balance between basic and complex calculations. As the MSC standard is intended to be globally applicable, basic attributes may be more appropriate. Our study suggests that in situations where information is limited, it is more appropriate to use a PSA specifically designed to incorporate attributes appropriate for evaluating impact on seabirds rather than other taxa.

4.2. Comparison of PSA, PBR and PVA

Although the PSA, PBR and PVA all produce different types of outputs, our study was designed with risk categories in mind that would allow a comparison of results. The high risk scores in the PBR and PVA for the wandering albatross case study contrast with the low and medium risk scores assigned using the MSC PSA v2.0. The high risk scores are consistent with the observed decline in the South Georgia population of approximately 1.8% per year during the period of the case study (Poncet et al. 2006, 2017). In addition, the seabird-specific PSA applied by Tuck et al. (2011) resulted in a high risk score for wandering albatrosses, which supports the use of a species group-specific type of PSA to ensure robustness and precaution.

The PBR results from the black-browed albatross case study were mostly high risk; the only low risk resulted from using the lowest bycatch estimate coupled with the least precautionary recovery factor. The PVA results were more varied, with half of the 6 scenarios indicating high risk. The observed decline of black-browed albatrosses at South Georgia between 1989/90 and 2003/04 was 4% per year (Poncet et al. 2006). There is high overlap between this population and demersal longline and trawl fleets off South Africa and Namibia, and with pelagic longline fisheries in the southwest Atlantic (Petersen et al. 2009, Jiménez et al. 2010, Clay et al. 2019). Therefore, the fishery considered here contributes to, but may not be the sole driver of, the population decline (Pardo et al. 2017). Regardless, the MSC PSA results are less precautionary than those from the other methods, where high risk levels indicate that the fishery is having an unsustainable impact.

The comparison of the approaches leads us to conclude that the MSC PSA v2.0 is not consistently robust and precautionary when it comes to assessing fishery impacts on seabirds. Our results show that this could lead to conclusions by management agencies that there is no need to prioritise action where that is clearly not the case, or to a fishery being certified as sustainable (with the associated ecolabel) when it is not. It could also lead to perverse situations where poor or uncertain data are used to evaluate risk with insufficient precaution and improved data to manage risks are therefore not sought. On the basis of many of these points, the MSC revised the PSA approach to focus on species-specific attributes in MSC PSA v3.0 (MSC 2023). We recommend that management agencies apply the new MSC PSA v3.0 or seabird-specific PSAs where other tools are not appropriate. We also recommend that current MSC-certified fisheries transition to the new Fisheries Standard v3.0 and apply the MSC PSA v3.0, where applicable, as soon as possible.

4.3. Identifying the appropriate methodology for fisheries risk assessments

This paper uses 3 different approaches to estimate risk of fisheries impacts on seabirds. However, a wide variety of other methods are available (e.g. as described by Le Bot et al. 2018). For example, New Zealand uses a spatially explicit fisheries risk assessment (SEFRA) to assess risk of fisheries impacts on seabirds, which has elements of PBR but includes explicit treatment of uncertainty, so it is possible to distinguish between results that have high impact and low uncertainty from those where there is high uncertainty and unknown impact (Sharp 2017). The SEFRA tool output provides an absolute value for risk, which can be used to identify high-risk species and fisheries as well as track changes in the overall risk status over time (Richard et al. 2020). This type of assessment is therefore more appropriate to apply than the PSA, where absolute risk scores are required.

When deciding on the most appropriate seabird risk assessment, 2 factors are important: the objective of the assessment, and the quality of the demographic and fishery-specific information. Where data are limited, qualitative and semi-quantitative approaches are the most appropriate and are useful for identifying if there is a bycatch problem and prioritising action. These approaches have been used in developing National Plans of Action for Seabirds (Good et al. 2020). We have developed a flow chart to assist with decision-making based on the seabird and fishery information available and objective of the risk assessment, noting that there are alternative methods not considered in our study (Fig. 3).

Although quantitative approaches such as PBR and PVA seem more appropriate than a PSA for determining a level of absolute risk, they require better data that link fishing mortalities to population-level impacts (Phillips 2013, Phillips et al. 2016). Moreover, possible problems with using PBR include: inappropriate use of 'rule of thumb' multipliers where demographic data are limited; use of underlying assumptions about density dependence and population trajectory that may not fit well with real-world seabird population dynamics; the inappropriate selection of a recovery factor; and the inappropriate interpretation of results in light of cumulative anthropogenic impacts (Dillingham & Fletcher 2011, O'Brien et al. 2017, Bakker et al. 2018). However, if these consider-

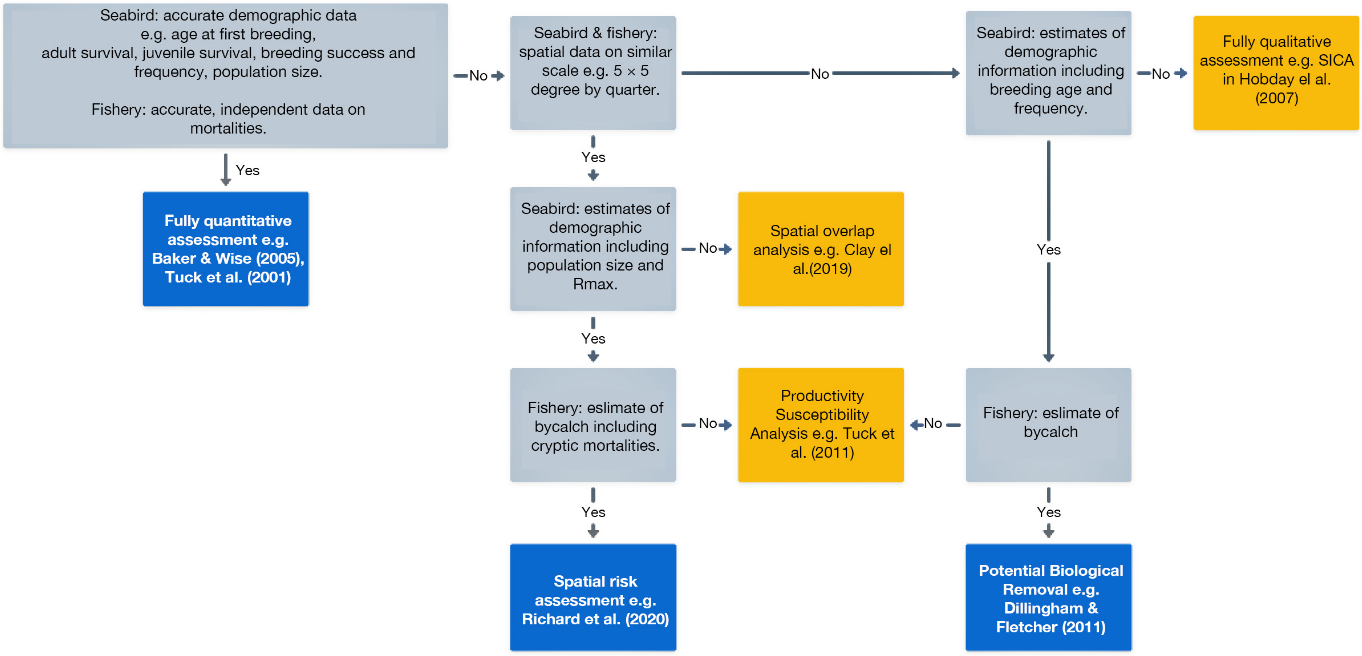

Fig. 3. Flow chart to assist with decision-making to select the most appropriate seabird–fisheries risk assessment tool, given the types of information available and objectives. Orange = methods recommended for prioritising data collection or management actions; blue = methods recommended for estimating whether impacts on a population are sustainable

ations are carefully considered, PBR can be a useful tool.

PVAs allow the user to examine implications of different harvest levels on population growth rate and probability of reaching a user-defined extinction threshold (Lacy 1993). We used the VORTEX tool as it is freely available and does not require modelling expertise, and hence is an accessible tool. The PVA relies on the input of robust demographic data, but the latter require long-term monitoring that continues for decades, given the extreme life histories of seabirds, and such studies are rare (Lewison et al. 2012). Even though our scenarios were based on demographic data obtained from studies over 40 yr in length (Pardo et al. 2017), we were still required to make assumptions such as that density dependence was not a factor for these populations. Other, more complex models may better account for this (e.g. Tuck et al. 2001, Thomson et al. 2009).

In addition, similar tools have been used to assess risks to seabird populations from other anthropogenic threats, namely wind farms. For example, a PVA tool has been developed for some North Atlantic seabird species (JNCC 2022), and a similar approach could be taken for a wider range of seabirds and impacts.

However, where assumptions are made, they should be acknowledged and communicated to stakeholders. If data are available, we recommend using risk assessment tools in combination, as we have in this study, and incorporation of a validation step that determines if results are consistent with estimated or observed population growth rates for any species for which sufficient data are available.

5. CONCLUSIONS

In this study, we demonstrated that the widely applied MSC PSA v2.0 is not a robust and precautionary tool for use in evaluating the risk of fishery impacts on seabirds. Instead, we recommend the use of alternatives including the new MSC PSA v3.0. It is particularly important to ensure that methods used to estimate risk are robust and precautionary, as the outputs are likely to be used to make management decisions and to assess a fisheries' sustainability. It takes decades for species with a low fecundity but high survivability such as albatrosses, petrels and most seabirds to recover from steep or prolonged population declines, and any delay in regulation and implementation of effective bycatch mitigation could have severe consequences.

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