The link between seabird traits and anthropogenic threats with implications for conservation

by © Cerridwen Richards

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Thesis Abstract

Seabirds are heavily threatened by anthropogenic activities and their conservation status is deteriorating rapidly. Key goals for successful management and conservation are to identify vulnerable species, and to evaluate conservation gains. Here, I couple a comprehensive dataset of traits with International Union for Conservation of Nature (IUCN) Red List extinction risk categories, and threat data for all 341 seabird species. I reveal seabirds segregate in trait space based on threat status, and anthropogenic impacts are selectively removing large, long-lived, pelagic surface feeders with small habitat breadths (Chapter 2). Furthermore, I quantify species' vulnerability to longline, trawl and purse seine bycatch, and find bycatch mitigation could successfully conserve species' traits at a global scale (Chapter 3). My results suggest targeted conservation strategies must be implemented to ensure a functionally similar suite of seabirds will not be lost in the near future.

Co-authorship Statement

I have made the primary intellectual and practical contribution to all work that is reported in this thesis.

Chapter 2

- I, **Cerren Richards**, designed and identified the research questions, analyzed the data, prepared the figures and tables, and authored the manuscript.
- **Robert S.C. Cooke** contributed body mass, clutch size, habitat breadth and diet guild trait data for 281 seabird species. Cooke further assisted with coding the random forest imputation approach in R and preparing its description for the manuscript (section 2.3.2).
- **Amanda E. Bates** assisted with the conceptualization of the manuscript.

Chapter 3

- I, **Cerren Richards**, designed and identified the research questions, analyzed the data, prepared the figures and tables, and authored the manuscript.
- **Robert S.C. Cooke** assisted with the conceptualization of the manuscript.
- **Diana Bowler** assisted with the conceptualization of the manuscript.
- **Kristina Boerder** contributed the Global Fishing Watch data.
- **Amanda E. Bates** assisted with the conceptualization of the manuscript, and assisted with coding the vulnerability framework in R.

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List of Abbreviations

IUCN	International Union for Conservation of Nature
CR	Critically Endangered
EN	Endangered
VU	Vulnerable
NT	Near Threatened
LC	Least Concern

AIS	Automatic Identification System
CWM	Community Weighted Mean
GAM	General Additive Model
MCA	Multiple Correspondence Analysis
PCA	Principal Component Analysis
PERMANOVA	Permutational Multivariate Analysis of Variance
SIMPER	Similarity of Percentages Analysis
UTC	Unique Trait Combination

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Chapter 1 Introduction

1.1 Background

1.1.1 Human induced pressures

Humans are driving rapid changes in the world's physical, chemical and biological makeup (Jenkins, 2003). Habitat transformation, species exploitation, climate change, pollution, and invasive species have the largest relative global impact (IPBES, 2019). These pressures are cumulative and have spread to all ecosystems, from the upper atmosphere to the deep sea (Woolmer et al., 2008; Halpern et al., 2008; Geldmann, Joppa & Burgess, 2014; Venter et al., 2016; Worm & Paine, 2016; Bowler et al., 2020). Consequently, up to an estimated one million animal and plant species are now threatened with extinction (IPBES, 2019), populations of vulnerable taxa are declining, and biological diversity is changing (Dornelas et al., 2014).

Biodiversity acts to stabilise ecosystem functioning under environmental fluctuations across temporal and spatial scales (Tilman, Isbell & Cowles, 2014). For example, the insurance hypothesis (redundancy) suggests biodiversity provides long-term insurance to buffer ecosystems against declines in their functioning because having many species provide greater guarantees that some will maintain functioning even if others fail (Yachi & Loreau, 1999). Yet, the loss and restructuring of biodiversity, through processes such as non-random species loss and trophic cascades, has profound implications for the resilience of ecosystem functions and services (Chapin et al., 2000; Cardinale et al., 2012; Mace, Norris & Fitter, 2012).

Extinctions under human pressures are not random, but depend on a number of species' attributes such as rarity, body size, small geographic range, habitat specialisation and sensitivity to environmental stress (Duffy, 2003; Gross & Cardinale, 2005; Rao & Larsen, 2010). Across birds, mammals, insects and plants, the most functionally important species (e.g., keystone species) are often the most prone to extinction (Rao & Larsen, 2010).

Consequently, their loss could disrupt processes related to nutrient dispersal and regeneration, predation, disturbance, and bioengineering activities (Rao & Larsen, 2010; Schmitz et al., 2018). Additionally, non-random species loss can generate cascading secondary extinctions that further disrupt species interactions (e.g., parasitism, competition, predation) and may directly affect ecosystem processes by modifying resource use and energy pathways (Rao & Larsen, 2010).

1.1.2 Traits and conservation

Traits are attributes of organisms, such as morphological, physiological, phenological and behavioural features, measured at the individual level without reference to the environment (Violle et al., 2007; Gallagher et al., 2020). Selecting meaningful and interpretable traits can relate to species' vulnerabilities (Table 1.1). For example, many ecological traits such as small geographic range, slow life history, and large body size, are strong predictors of extinction risk in birds and mammals (Davidson et al., 2009; Peñaranda & Simonetti, 2015; Cooke, Eigenbrod & Bates, 2019). Furthermore, when traits relate to function, they can be used to understand how species interact with their environment, and to assess species' contributions to ecosystem processes (Gallagher et al., 2020; Table 1.1). Thus, combinations of traits can summarise a species' ecological role (Brum et al., 2017), and species can be grouped based on ecologically similar strategies (Cooke, Eigenbrod & Bates, 2019).

Traits are powerful tools that have facilitated targeted conservation strategies and transformational insights into fundamental ecological and biogeographical questions across multiple levels of biological organisation and spatial scales (Lamanna et al., 2014; Belmaker & Jetz, 2015; Pollock, Thuiller & Jetz, 2017). At a species level, traits can be integrated into frameworks along with exposure patterns to quantify species' vulnerability to threats (Foden et al., 2013; Potter, Crane & Hargrove, 2017). Traits can also be used to quantify community resilience to environmental and anthropogenic pressures (Buisson et al., 2013; Mori, Furukawa & Sasaki, 2013; Belmaker, Parravicini & Kulbicki, 2014). Traits have played a key role in shifting global biodiversity patterns from a species richness dominated view to indices that describe species contributions to ecosystem processes and functioning e.g., functional diversity, uniqueness, distinctiveness, and community weighted mean (McGill et al., 2006; Stuart-Smith et al., 2013; Gustafsson & Norkko, 2019). Revealing these patterns allows development of proactive conservation strategies such as targeting high risk species, enhancing biodiversity and preserving ecosystems (Murray et al., 2011; Peñaranda & Simonetti, 2015; Potter, Crane & Hargrove, 2017; Butt & Gallagher, 2018).

There are a number of important considerations for trait-based studies including trait selection, coverage, correlation and standardisation. Since the 1990s, the collection and accessibility of trait data for trait-based studies has accelerated rapidly (Gallagher et al., 2020). While trait selection is flexible, blind compilation simply because the trait information is available will likely yield spurious and irrelevant results, and should be avoided (Beauchard et al., 2017). Selection should be interpretable and relevant to the research objectives (Magurran, 2004; Beauchard et al., 2017). Furthermore, when selecting traits, it is also important that they have broad (>50%) species coverage (Laliberté & Legendre, 2010a). An advantageous solution to increase coverage is through the imputation approach which replaces missing data with substituted values. Imputations increase the sample size and consequently the statistical power of any analysis whilst reducing bias and error (Taugourdeau et al., 2014; Penone et al., 2014; Kim, Blomberg & Pandolfi, 2018). Using heterogenous or correlated traits (e.g., feeding mode and diet) can create numerical noise without objective biological meaning (Beauchard et al., 2017). However, these trait types should not necessarily be disregarded. Traits may be correlated owing to physical constraints, yet can relate to distinct ecological processes (Lepš et al., 2006). Thus, to capture these differences, it may be important to include correlated traits (Magurran, 2004). Traits are often compiled from multiple sources and likely have different units, ranges and variances. Scaling and standardising the trait data through transformations can equalize these issues (Magurran, 2004; Villéger, Mason & Mouillot, 2008; Laliberté & Legendre, 2010).

Table 1.1 Eight traits used in this thesis and how they relate to ecosystem functioning and species' vulnerabilities. Ecosystem function column modified from Tavares et al. (2019)

Trait	**Ecosystem Function**	**Species' Vulnerability**	**Example**
Body Mass	Nutrient storage and transport.	Strong predictor of extinction risk.	Cooke et al. (2019)
Habitat Breadth	Nutrient transport. Community shaping through organism dispersal.	Range of exposure to threats, whether the species can move to different habitat types or is limited to one habitat type.	Cooke et al. (2019)
Generation Length	Nutrient storage.	Describes reproductive speed and represents the ability of populations to recover from threats.	BirdLife International
Clutch Size	Nutrient storage.	Describes reproductive speed and represents the ability of populations to recover from threats.	Cooke et al. (2019)
Pelagic Specialism	Nutrient transport.	Exposure and interaction with marine threats such oil spills and bycatch.	Wilman et al. (2014).
Migration	Seasonal nutrient transport. Community shaping through organism dispersal. Seasonal shaping of prey populations.	Experience different threats depending on their breeding and wintering locations.	BirdLife International
Foraging Guild	Nutrient storage. Trophic-dynamic regulations of populations.	The propensity of species to interact with threats e.g., bycatch.	Wilman et al. (2014).

Diet	Nutrient storage. Trophic-dynamic regulations of populations.	Sensitive to overexploitation of specific foods (e.g., overfishing) and changes in lower trophic levels.	Cooke et al. (2019)

1.1.3 Seabirds as a model for trait-based ecology

Seabirds are iconic marine organisms of international importance. As top predators, seabirds play a key role in marine ecosystem functioning through nutrients transportation, trophic regulation and community shaping (Tavares et al., 2019; Table 1.1). Seabirds are also acknowledged as bioindicators of ocean health (Parsons et al., 2008; Velarde, Anderson & Ezcurra, 2019) because slow life history traits, such as small clutch size and long generation lengths, leave seabirds sensitive to natural and anthropogenic pressures. Thus, small changes at lower trophic levels and in the physico-chemical environment can manifest at the population level (Bost & le Maho, 1993; Parsons et al., 2008).

As an exceptionally well-studied group, seabirds are excellent models for trait-based studies. These birds require isolated terrestrial landmasses to breed therefore can be monitored throughout the breeding season. Furthermore, recent technological gains through miniaturization of biologging devices has revealed their behaviours at sea and during the winter (Wakefield, Phillips & Matthiopoulos, 2009; Votier et al., 2010; Fayet et al., 2017; Richards et al., 2019). Consequently, vast information is available on the life history, behavioural and ecological traits of seabirds.

One third of all seabird species are globally threatened and half are experiencing population declines (Croxall et al., 2012; Paleczny et al., 2015; Dias et al., 2019; IUCN, 2020). As wide-ranging foragers, seabirds are exposed to multiple and repeated threats across the marine-terrestrial ecotone (Fig. 1.1). In the marine environment, threats such as bycatch, overfishing and pollution directly and indirectly affect the survival of seabirds. On land, invasive species, habitat modification and human disturbance are threatening breeding success. These threats interact with traits to endanger some species, but not others (Murray et al., 2011). Using traits as a tool could help filter species most vulnerable to anthropogenic threats (Zhou, Jiao & Browder, 2019), and assist with creating target conservation strategies.

Figure 1.1 Examples of anthropogenic threats facing seabirds across the marine-terrestrial interphase. Graphic by Rachel Hudson, with permission from Rachel Hudson and BirdLife International.

1.1.4 Conservation goals and resources

Central goals of conservation science are understanding the effects and extent of threats on nature and assessing whether pressures change in response to conservation actions

(Geldmann, Joppa & Burgess, 2014). Through international commitment, many organisations, resources and initiatives have arisen to tackle these challenges. Examples include categorising species by extinction risk to catalyse species' conservation prioritisation (e.g., the International Union for Conservation of Nature (IUCN) Red List - *iucnredlist.org*), and building databases of species and threat distributions to quantify species exposure to threats through space and time (e.g., BirdLife International - *birdlife.org*, Global Fishing Watch - *globalfishingwatch.org*).

The IUCN Red List of Threatened Species is the most comprehensive information source on the global conservation status of biodiversity (IUCN, 2020). This powerful tool classifies species into nine categories of global extinction risk: Not Evaluated, Data Deficient, Least Concern, Near Threatened, Vulnerable, Endangered, Critically Endangered, Extinct in the Wild and Extinct (Fig. 1.2). The IUCN Red List also provides information about species' range, population size, habitat and ecology, threats and conservation actions. To date, more than 112,400 species have been assessed. BirdLife International is a world leader in the conservation of birds, their habitats and global biodiversity. Together with the Handbook of the Birds of the World, they have compiled distribution maps for over 11,000 bird species (BirdLife International, 2017). Global Fishing Watch is a revolutionary platform that monitors global fishing activity in near real-time. The resource is used for scientific research, to advocate for marine protection, tackle overfishing and improve fishing management.

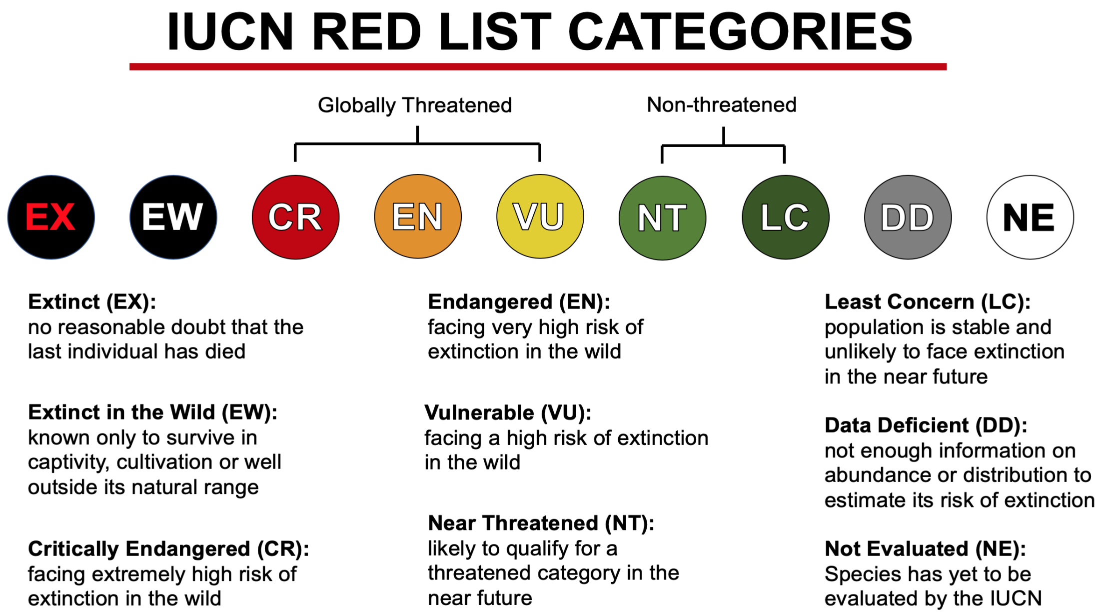


Figure 1.2 IUCN Red List classifies species into nine categories of extinction risk. Modified from iucnredlist.org.

1.2 Thesis overview and objectives

Very few studies have taken trait-based approaches for seabirds (Tavares et al., 2019; Zhou, Jiao & Browder, 2019; Pimiento et al., 2020). Therefore, it remains an open question whether traits can be as an effective tool to elucidate patterns of seabird extinction risk and vulnerabilities to anthropogenic threats. Furthermore, whether traits could be useful to strengthen conservation planning and implementation. Over two chapters, I couple a comprehensive dataset of seabird traits with IUCN Red List extinction and threat categories, BirdLife International distribution maps, and Global Fishing Watch data to:

1) **Estimate** species' vulnerability patterns;
2) **Quantify** the extent mitigation methods may successfully conserves species' traits within communities;
3) **Inform** conservation priorities for seabirds.

1.2.1 Chapter Two - Biological traits of seabirds predict extinction risk and vulnerability to anthropogenic threats

1.2.1.1 Objectives

1) To test whether species are separated in trait space based on extinction risk;
2) To quantify the redundancy of species' traits based on extinction risk;
3) To identify whether ecologically similar seabird species are responding similarly to human pressures.

1.2.1.2 Main findings

- Globally and non-threatened seabirds occupy ecologically distinct areas in trait space.
- There is greater redundancy in traits of globally threatened species and greater uniqueness in traits of non-threatened species. Therefore, we are losing species with similar traits and ecological strategies.
- Traits related to specialization (habitat breadth, diet and pelagic specialism) explain the difference between species with and without threats. Whereas reproductive speed traits (clutch size and generation length) differentiate between species threatened by direct, habitat or no threats.

1.2.2 Chapter Three - Using ecological traits to quantify seabird bycatch vulnerability and predict conservation gains

1.2.2.1 Objectives

1) To quantify species' gear-specific vulnerability to bycatch using a systematic framework;
2) To map and describe the spatial variation in community traits;
3) To predict whether successfully mitigating fisheries bycatch will prevent shifts in traits of seabird communities.

1.2.2.2 Main Findings

- Species traits exhibit distinct spatial variation across the globe meaning this reveals important conservation locations for specific seabird traits and ecological roles.
- Mitigating fisheries bycatch could prevent significant shifts in the traits of seabird communities particularly between 30° - 70° in both hemispheres.
- We categorise species into longline, trawl, and purse seine vulnerability classes and provide management approaches for each category.

Chapter 2 Traits of seabirds predict extinction risk and vulnerability to anthropogenic threats

2.1 Abstract

Seabirds are heavily threatened by anthropogenic activities and their conservation status is deteriorating rapidly. Yet, these pressures are unlikely to uniformly impact all species. It remains an open question if seabird species with similar ecological roles are responding in synchrony to human pressures. Here we compile and impute eight traits across all 341 species of seabird. We test whether globally-threatened vs non-threatened seabirds are separated in trait space and identify traits that render species vulnerable to anthropogenic threats. Seabirds segregate in trait space based on threat status where anthropogenic impacts are selectively removing large, long lived, pelagic surface feeders with small habitat breadths. We further find that species with small habitat breadths and fast reproductive speeds are more likely to be threatened by habitat-modifying processes; whereas pelagic specialists with slow reproductive speeds are vulnerable to threats that directly impact survival and fecundity. Our results suggest targeted conservation strategies must be implemented to ensure a functionally similar suite of seabirds will not be lost in the near future, and supports that targeted conservation measures will have positives impacts for many species.

2.2 Introduction

Humans are increasing the proportion of endangered species and causing widespread extinctions (Vié, Hilton-Taylor & Stuart, 2009; Barnosky et al., 2011; IPBES, 2019). Consequently, signs of a sixth mass extinction event are unfolding worldwide (Barnosky et al., 2011). Presently, nearly 800 animals have been documented as “Extinct” since 1500 (IUCN, 2020) including a number of seabird species such as the great auk (*Pinguinus impennis),* spectacled cormorant *(Urile perspicillatus),* and small St Helena petrel *(Bulweria bifax).* Habitat transformation, species exploitation, climate change, pollution, and invasive species are recognised as the most pervasive threats driving species extinctions and biodiversity change worldwide (Woolmer et al., 2008; Halpern et al., 2008; Geldmann, Joppa & Burgess, 2014; Venter et al., 2016; Worm & Paine, 2016; IPBES, 2019; Bowler et al., 2020).

Species traits are useful tools to understand why some species are more vulnerable to threats and have greater extinction risks (Peñaranda & Simonetti, 2015). Traits are attributes or characteristics of organisms measured at the individual level (Violle et al., 2007; Gallagher et al., 2020). These include morphological, physiological, phenological and behavioural features such as body mass, reproductive speed, diet and habitat breadth. Selecting meaningful and interpretable species' traits can relate to ecosystem functions and species' vulnerabilities. For example, a species' diet captures regulation of trophic-dynamics and nutrient storage functions, and its sensitivity to changes at lower trophic levels. Thus, combinations of traits can summarise a species' ecological role (Brum et al., 2017), and species can be grouped based on ecologically similar strategies (Cooke, Eigenbrod & Bates, 2019).

Extinctions under human pressures are not random, but depend on a number of species' traits such as body size, small geographic range, habitat specialisation and slow life history (Duffy, 2003; Gross & Cardinale, 2005; Davidson et al., 2009; Rao & Larsen, 2010; Peñaranda & Simonetti, 2015; Cooke, Eigenbrod & Bates, 2019). Therefore, threats likely target ecologically similar groups of species, while species with generalist traits, for example, omnivorous diets and large habitat breadths, may offer protection against extinction risks (Cooke, Eigenbrod & Bates, 2019). Elucidating patterns and drivers of species extinction risk will likely provide the opportunity to develop more informed and effective conservation strategies (Ripple et al., 2017).

Seabirds are the most threatened group of birds and their status is deteriorating rapidly (Croxall et al., 2012; Paleczny et al., 2015). Seabirds are well adapted for life in the marine environment owing to their life history and ecological strategies including long life span, low fecundity and specialised foraging strategies e.g., diving for prey underwater. These traits likely evolved to optimise adult survival because delivering food to offspring from the open ocean requires large effort (Velarde, Anderson & Ezcurra, 2019). However, seabirds require isolated terrestrial landmasses to breed during the breeding season. This requirement exposes seabirds to multiple and repeated anthropogenic threats in both the marine and terrestrial environment. These threats include those that directly affect survival and fecundity (e.g., invasive species, bycatch), threats that modify or destroy habitat (e.g., land modification, energy production) and global change threats (e.g., climate change) (Croxall et al., 2012; De Palma et al., 2015; Dias et al., 2019; Rodríguez et al., 2019).

As an exceptionally well-studied group, seabirds are excellent models for trait-based studies. These birds are heavily monitored throughout the breeding season at colonies across the world. Furthermore, recent technological gains through miniaturization of biologging devices has revealed seabird foraging behaviours at sea and during the winter (Richards et al., 2019). Thus, vast information is available on the life history, behavioural and ecological traits of seabirds. However, few studies have investigated the macroecological patterns of seabird threat risks. It remains an open question how ecological strategies of seabirds expose them to specific anthropogenic threats, and what consequence this has for ecosystem functioning.

Here we compiled and imputed eight traits across 341 seabird species from multiple databases to firstly test whether species are separated in trait space based on extinction risk. We predict globally threatened species will occupy distinct regions of trait space because threats act on traits non-randomly (Duffy, 2003; Gross & Cardinale, 2005; Rao & Larsen, 2010). Secondly, we quantify the redundancy of species traits based on extinction risk (IUCN category). If pressures are targeting species with similar ecological strategies, we expect a greater redundancy in the traits of globally threatened species. Finally, we identify whether ecologically similar seabird species are responding similarly to human pressures. We expect to find species with small habitat breadths to be at risk from habitat threats. Species with low reproductive speeds will be affected by pressures that directly affect survival and fecundity. Species with no threats will be generalists with fast reproductive speeds.

2.3 Methods

2.3.1 Trait selection and data

We compiled data from multiple databases for eight traits across all 341 species of seabird, excluding marine ducks (Table 2.1). These traits were selected to encompass the varying ecological and life history strategies of seabirds, because they relate to ecosystem functioning and species' vulnerabilities, and because they had excellent coverage across >80% of seabird species (Chapter One, Table 1.1). We first extracted the trait data for body mass, clutch size, habitat breadth and diet guild from a recently compiled trait database for birds (Cooke, Bates & Eigenbrod, 2019). Generation length and migration status were compiled from BirdLife International (datazone.birdlife.org), and pelagic specialism and foraging guild from Wilman et al. (2014).

Foraging and diet guild describe the most dominant foraging strategy and diet of the species. Wilman et al. (2014) assigned species a score from 0 to 100% for each foraging and diet guild based on their relative usage of a given category. Using these scores, species were classified into four foraging guild categories (diving, surface, ground and generalist foragers) and three diet guild categories (omnivore, invertebrates and VertFishScav: Vertebrates, Fish and Carrion). Each was assigned to a guild based on the predominant foraging strategy or diet (score > 50%). Species with two equally weighted categories, or all category scores <50% were classified as generalists for the foraging guild trait and omnivores for the diet guild trait. Body mass is the median body mass in grams. Habitat breadth is the number of habitats listed as suitable by the International Union for Conservation of Nature (IUCN, iucnredlist.org). This encompasses the variety of habitats that species occupy throughout their lifetimes, for example, Arctic dessert, marine intertidal, wetland, urban areas, and marine oceanic. Generation length describes the age at which a species produces offspring in years. Clutch size is the number of eggs per clutch. Migration status describes whether a species undertakes full migration or not. Pelagic specialism describes whether foraging is predominantly pelagic. While pelagic specialism and habitat breadth traits closely align, we retain both traits because pelagic specialism captures the distinct habitat use at sea where bycatch, the greatest threats to seabirds, occurs (Dias et al., 2019). We $\log_{10}$ transformed body mass, habitat breadth, and generation length traits to make the trait units more understandable for the analyses.

2.3.2 Multiple imputation

To achieve complete species trait coverage, we imputed missing data for clutch size (4 sp.), generation length (1 sp.), diet guild (60 sp.), foraging guild (60 sp.), pelagic specialism (60 sp.) and migration status (3 sp.). Body mass and habitat breadth had complete species coverage (Table 2.1). The imputation approach has the advantage of increasing the sample size and consequently the statistical power of any analysis whilst reducing bias and error (Taugourdeau et al., 2014; Penone et al., 2014; Kim, Blomberg & Pandolfi, 2018).

We estimated missing values using random forest regression trees, a non-parametric imputation method, based on the ecological and phylogenetic relationships between species (Stekhoven & Bühlmann, 2012). This method has high predictive accuracy and the capacity to deal with complexity in relationships including non-linearities and interactions (Cutler et al., 2007). To perform the random forest multiple imputations, we used the *missForest* function from package "missForest" (Stekhoven & Bühlmann, 2012), based on 1,000 trees. We imputed missing values based on the ecological (the trait data) and phylogenetic (the first 10 phylogenetic eigenvectors, detailed below) relationships between species. Due to the predictive nature of the regression tree imputation approach, the estimated values will differ slightly each time. To capture this imputation uncertainty and to converge on a reliable result, we repeated the process 15 times, resulting in 15 trait datasets (van Buuren & Groothuis-Oudshoorn, 2011; González-Suárez, Zanchetta Ferreira & Grilo, 2018). We take the mean values for continuous traits and modal values for categorial traits across the 15 datasets for subsequent analyses.

Phylogenetic information was summarised by eigenvectors extracted from a principal coordinate analysis, representing the variation in the phylogenetic distances among species (Diniz-Filho et al., 2012a,b). Bird phylogenetic distance data (Prum et al., 2015) were input into R using the *read.tree* function from package "ape" (Paradis, Claude & Strimmer, 2004) and decomposed into a set of orthogonal phylogenetic eigenvectors using the *Phylo2DirectedGraph* and *PEM.build* functions from the "MPSEM" package (Guenard & Legendre, 2018). Here, we used the first 10 phylogenetic eigenvectors, ensuring a balance between including detailed phylogenetic information and diluting the information contained in the other traits. The first 10 eigenvectors in our data represented 61% of the variation in the phylogenetic distances among seabirds. Phylogenetic data can improve the estimation of missing trait values in the imputation process (Swenson, 2014; Kim, Blomberg & Pandolfi, 2018). This is because closely related species tend to be more similar to each other (Pagel, 1999) and many traits display high degrees of phylogenetic signal (Blomberg, Garland & Ives, 2003). While imputation error is minimised when including the first 10 phylogenetic eigenvectors as variables in the imputations (Penone et al., 2014), these phylogenetic eigenvectors are more representative of divergences closer to the root of the phylogeny and do not include fine-scale differences among species (Diniz-Filho et al., 2012a).

To quantify the average error in random forest predictions across imputed datasets (out-of-bag error), we calculated the normalized root mean squared error for continuous traits (clutch size = 13%, generation length = 0.6%) and percent falsely classified for categorical traits (diet guild = 29%, foraging guild = 18%, pelagic specialism = 11%, migration status = 19%). Since body mass and habitat breadth have complete trait coverage, their out-of-bag error is 0%. Low imputation accuracy is reflected in high out-of-bag error values. Therefore, diet guild had the lowest imputation accuracy with 29% wrongly classified on average.

2.3.3 Sensitivity

To compare whether our results and conclusions were quantitatively and qualitatively similar between the imputed and non-imputed datasets, we ran all of our analyses with and without the imputed data.

Table 2.1 Eight traits and their description used in the present study. Imputation indicates the number of species imputed.

Trait	Type	Description	Imputations	Source
Body Mass	Continuous	Log_{10} (median body mass in grams).	0	Cooke et al. (2019)
Habitat Breadth	Continuous	Log_{10} (number of IUCN habitats listed as suitable).	0	Cooke et al. (2019)
Generation Length	Continuous	Log_{10} (generation length in years).	1	BirdLife International
Clutch Size	Continuous	Number of eggs per clutch.	4	Cooke et al. (2019)
Pelagic Specialism	Categorical	Is the species a pelagic specialist? *Yes* *No*	60	Wilman et al. (2014)
Migration	Categorical	Does migration occur? *Full migrant* *Non-migrant*	3	BirdLife International
Foraging Guild	Categorical	The dominant foraging guild of the species. *Generalists* *Diver* *Surface Feeder* *Ground Feeder*	60	Wilman et al. (2014)
Diet	Categorical	The dominant diet of the species. *Omnivore* *Invertebrates* *Vertebrates & Scavengers*	60	Cooke et al. (2019)

2.3.4 Species extinction risk

The International Union for Conservation of Nature's (IUCN) Red List of Threatened Species (iucnredlist.org) is the most comprehensive information source on the global conservation status of biodiversity (IUCN, 2020). This powerful tool classifies species into nine categories of extinction risk. Here we use five IUCN Red List categories to group extant species into broader global risk groups. Species categorised as critically endangered (CR), endangered (EN) and vulnerable (VU) were defined as *globally threatened*, and species classified as near threatened (NT) and least concern (LC) were defined as *non-threatened*.

2.3.5 Principal component analysis of mixed data

To quantify the trait space shared by globally and non-threatened seabirds, we ordinated 341 seabirds based on eight traits with a principle component analysis (PCA) of mixed data. We used the package "PCAmixdata" and function *PCAmix* (Chavent et al., 2017). PCA of mixed data takes a two-step approach through merging the standard PCA with multiple correspondence analysis (MCA) (Chavent et al., 2014). For continuous data, PCAmix is a standard PCA, whereas for categorical data, PCAmix it is an MCA (Chavent et al., 2014). To quantify the degree to which threat status explains trait space variations among seabirds, we use the permutational MANOVA framework in the *adonis* function and package "vegan" (Oksanen et al., 2018).

2.3.6 Trait-level distributions and proportions

To test whether the traits of globally threatened and non-threatened seabirds are different at the individual trait level, we explore the distributions of continuous traits and proportions of categorical traits per threat category. To test for differences in the means of threatened and non-threatened species within continuous traits, we ran Mann-Whitney U tests using base R and function *wilcox.test*. We further calculate Hedge's g effect size with function *hedges_g* and package 'effectsize' (Ben-Shachar, Makowski & Lüdecke, 2020). For categorical traits, we test for independence with a Chi-squared approach using base R and function *chisq.test*.

2.3.7 Unique trait combinations

To quantify the redundancy and uniqueness of species trait combinations per IUCN Red List Category, we use unique trait combinations (UTCs). Here UTC is defined as the proportion of species with trait combinations that are not found in other seabird species. To compute the UTCs of the 341 seabirds, we broke the continuous traits into three equally spaced bins (small, medium and large) between min to max values. Following this, the proportion of UTCs within each IUCN Red List Category was calculated as a percentage.

Table 2.2 IUCN reclassified threat categories. 'Direct' threats directly affect survival and fecundity. 'Habitat' threats modify or destroy habitat. 'No threats' encompasses species with no identified IUCN threats. 'Other' threats are indirectly or not caused by humans Modified from Gonzalez-Suarez, Gomez & Revilla (2013).

Threat Reclassification	IUCN Threat
Direct	Biological resource use Invasive & other problematic species & genes Human intrusions and disturbance
Habitat	Residential and commercial development Agriculture and aquaculture Energy production and mining Transportation and service corridors Natural system modifications Pollution
No Threats	No threats
Other	Climate change and severe weather Geological events

2.3.8 Seabird Threats

We extracted the past, present and future threats for 341 seabirds from the IUCN Red List database using the function *rl_threats* and package "rredlist" (Chamberlain, 2018). These data have recently been updated in a quantitative review from >900 publications (Dias et al., 2019), and are classified into 12 broad types (Table 2.2). We reclassified the IUCN threats into four general categories: (1) *direct* – threats that directly affect survival and fecundity; (2) *habitat* - threats that modify or destroy habitat; and (3) *no threats* – species with no identified IUCN ; and (4) *other* – threats that are indirectly or not caused by humans (Gonzalez-Suarez, Gomez, & Revilla, 2013; Table 2.2). We excluded *other* threats (climate change and severe weather, and geological events) from our analyses because they are not directly linked to anthropogenic activity.

2.3.9 SIMPER analysis

To identify which traits explain the greatest difference between threats, we take a similarity of percentages (SIMPER) approach using the function *simper* in package "vegan" (Oksanen et al., 2018). SIMPER typically identifies the species that contribute the greatest dissimilarity between groups (levels) by disaggregating the Bray-Curtis similarities between inter-group samples from a species abundance matrix (Clarke & Warwick, 2001). Here, we assembled a trait by threat matrix, where traits are each level of the categorical and binned continuous traits (23 levels) and threats are the IUCN threat categories (10 levels; Table 2.2). For each threat, we calculated the proportion of species in each trait category. The reclassified IUCN threats were used to isolate the traits that contribute the greatest difference between habitat threats, direct threats and no threats.

All analyses were performed in R version 3.5.0 (R Core Team, 2018).

2.4 Results

2.4.1 Threat status segregation in multidimensional trait space

We find globally threatened species are qualitatively and statistically distinct from non-threatened species in terms of their biological trait diversity (PERMANOVA, $R^2 = 0.127$, $p = 0.001$; Fig. 2.1). Together, the first two dimensions (identified herein as "Dim1" and "Dim2") of the mixed data PCA explain 41% of the total trait variation (Fig. 2.1). Dim1 integrates reproductive speed, the trade-off between clutch size (loading = 0.860) and generation length (loading = -0.695), invertebrate diet (loading = -0.875), scavenger diet (loading = 0.643), omnivore diet (loading = -0.193), pelagic specialism (loading = -0.308), non-pelagic specialism (loading = 1.338) and surface foragers (loading = -0.850). Species with high Dim1 scores are typically characterised as non-pelagic scavengers with fast reproductive speeds e.g., cormorants, gulls and terns. Species with low Dim1 values have slow reproductive speeds and are pelagic surface foragers with diets high in invertebrates e.g., albatross, petrels, shearwaters and storm-petrels. Dim2 integrates body mass (loading = -0.330), full migrants (loading = 0.370), non-migrants (loading = -1.104), divers (loading = -0.969), generalists (loading = 0.972) and ground (loading = 1.509) foraging strategies. Species with high Dim2 are small bodied ground or generalist foragers e.g., gulls, terns, skuas and jaegers while those with low Dim2 are large bodied non-migrating divers e.g., shags, boobies and penguins.

Ten species fall outside the 95% confidence interval ellipse for globally threatened species. These include eight Laridae (Black-billed Gull, Black-fronted Tern, Relict Gull, Black-bellied Tern, Chinese Crested Tern, Indian Skimmer, Aleutian Tern, Lava Gull), one Phalacrocoracidae (Chatham Islands Shag) and one Spheniscidae (Galapagos Penguin).

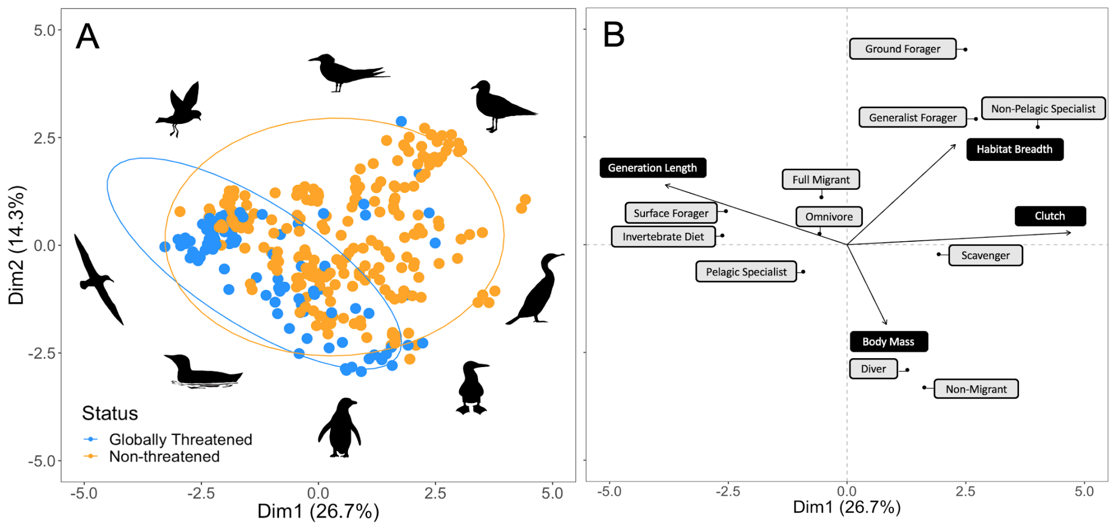
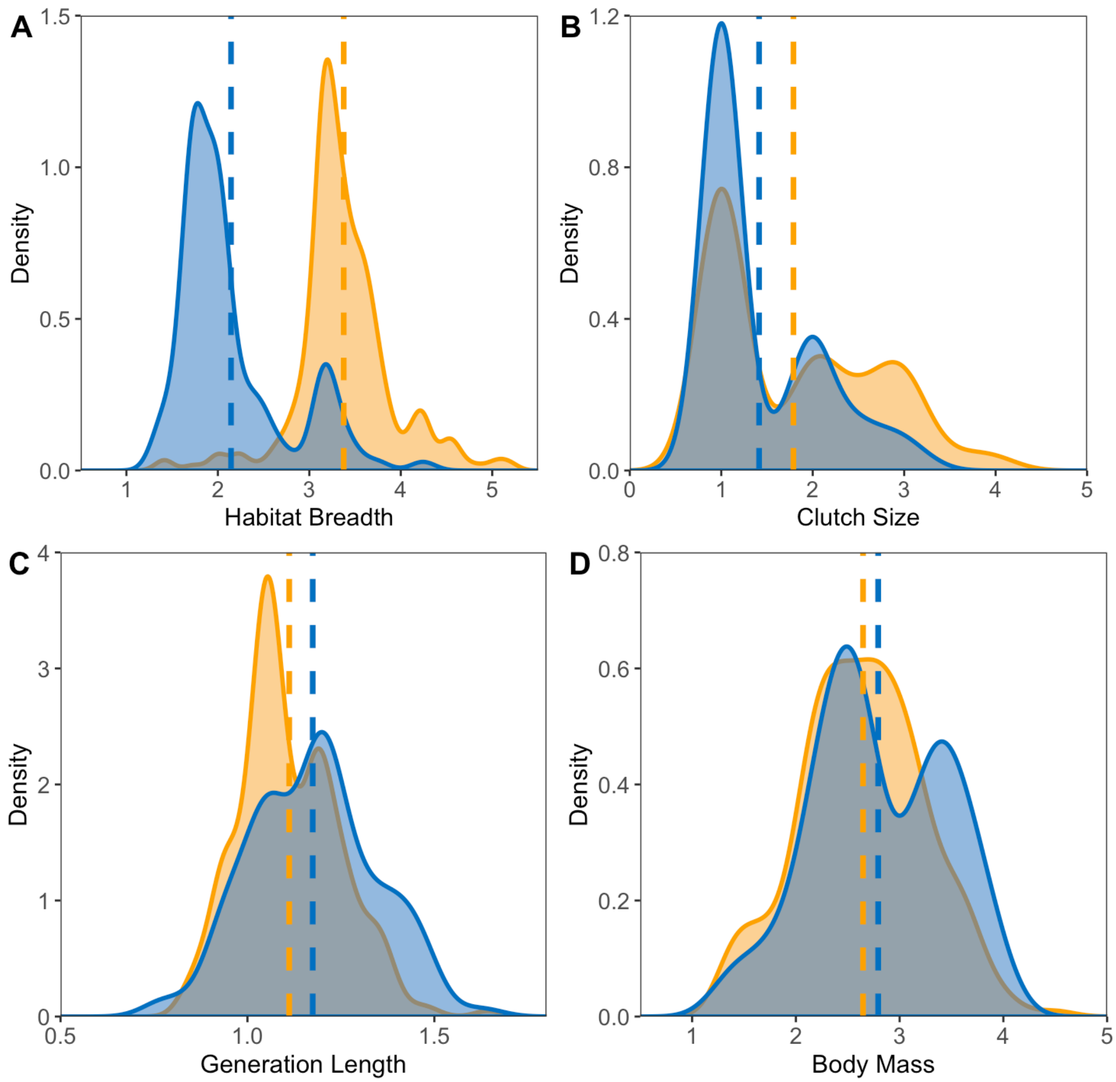


Figure 2.1 Mixed data PCA biplot of seabird traits. A) Points are the principal component scores of each seabird (mean values across 15 imputed datasets). Ellipses indicate the 95% confidence intervals for globally threatened (blue) and non-threatened (orange) seabird species. Silhouettes represent a selection of families aggregated at the edge of trait space. B) Coordinates of continuous (black) and categorical (white) traits.

2.4.2 Individual trait differences

We find a significant difference in six traits between globally threatened and non-threatened species (Fig. 2.2; Table 2.3). Specifically, habitat breadths of globally threatened species are 2.2x smaller [95% ci: -2.50, -1.94] than non-threatened seabirds, clutch sizes are 0.47x smaller [95% ci: -0.70, -0.24], and generation lengths are 0.44x longer [95% ci: 0.21, 0.67]. Compared to non-threatened species, we find globally threatened species have 18.6% more pelagic specialists, 26.2% more surface foragers, 4.8% fewer divers, 4.2% fewer ground foragers, 17.3% fewer generalist foragers, 31.7% fewer species with invertebrate diets, 22.6% greater species with fish and carrion diet, and 9.1% greater species with omnivore diets. There was no difference in the body mass or migration traits between globally and non-threatened species. We therefore find globally-threatened species are typically surface feeders with a diet higher in fish and carrion. They are mostly pelagic specialists that have small habitat breadths, small clutch sizes and long generation times. In comparison, non-threatened species are typically generalist foragers with a diet high in invertebrates. These species also typically have shorter generation lengths and larger clutch sizes with a larger habitat breadth and less pelagic specialism.



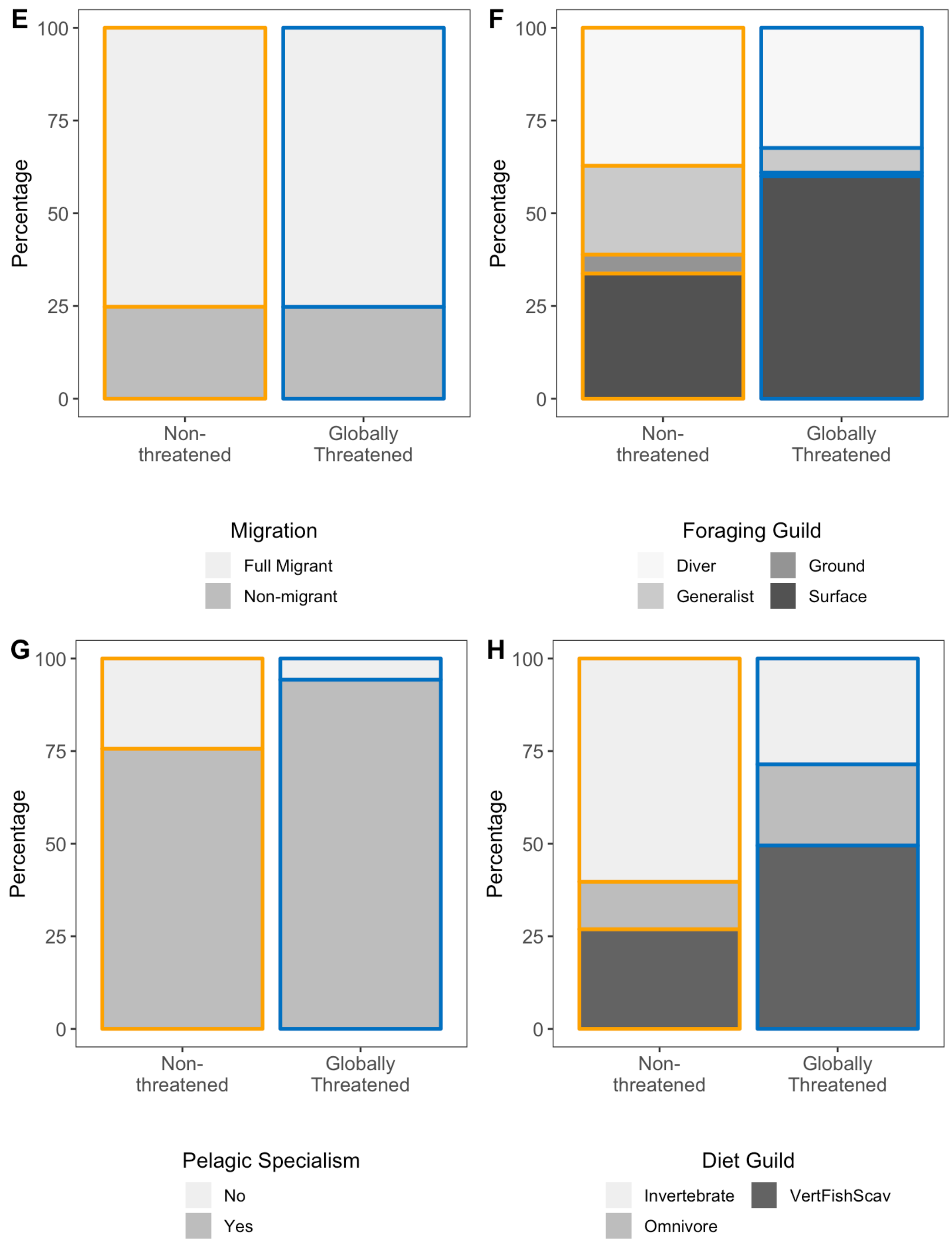


Figure 2.2 Trait distributions of continuous traits (A) habitat breadth, B) clutch size, C) generation length, D) body mass), and proportion of categorical traits (E) migration, F) foraging guild, G) pelagic specialism, H) diet guild). Orange represents non-threatened species, while blue represents globally threatened species.

Table 2.3 Test outputs for the difference in traits between globally threatened and non-threatened species.

Continuous Trait	**Mann-Whitney U (W)**	**p-value**
Body Mass	13652	0.0760
Clutch Size	9294	0.0001
Habitat Breadth	2059.5	0.0000
Generation Length	15186	0.0003
Categorical Trait	**Chi-squared (X^2)**	**p-value**
Diet Guild	32.106	0.0000
Pelagic Specialism	15.689	0.0000
Foraging Guild	28.174	0.0000
Migration	1.0394e-29	1.0000

2.4.3 Trait redundancy and uniqueness

We classified 165 different trait combinations across 341 seabirds. Of these, 58% are composed of only one species (n = 96) and are defined as unique trait combinations (UTCs). The proportion of UTCs decreases with increasing IUCN threat level (Fig 2.3). Consequently, a greater proportion of non-threatened species (31%) contribute UTCs than globally threatened species (22%). We, therefore, find greater redundancy in traits of globally threatened species and greater uniqueness in traits of non-threatened species (Fig. 2.3).

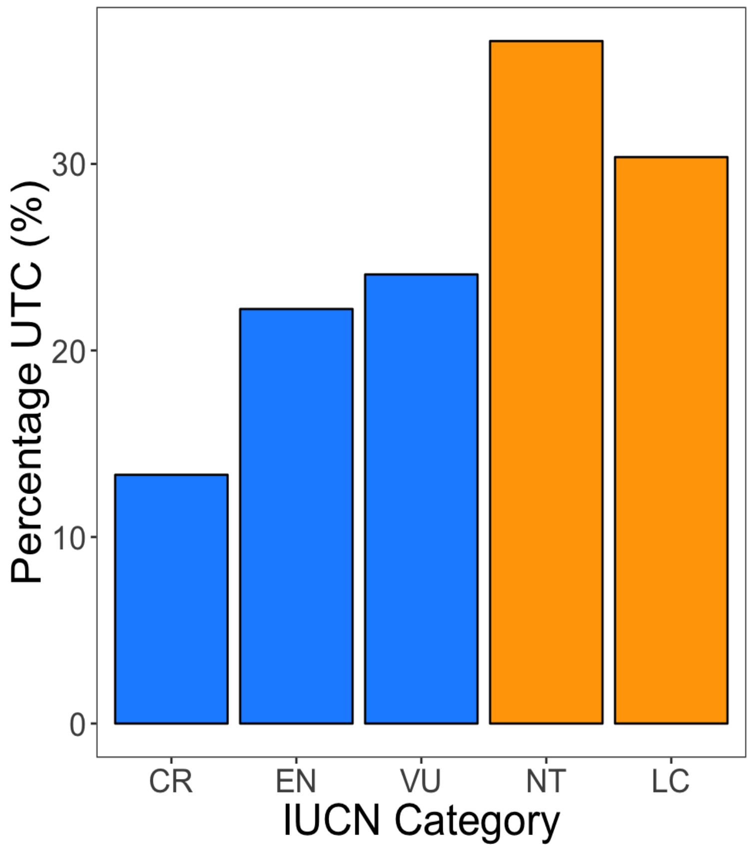


Figure 2.3 Proportion of seabird species with unique trait combinations for each IUCN category. Orange represents non-threatened categories and blue represents globally threatened categories.

2.4.4 SIMPER

Similarity percentages analysis (SIMPER) identifies the combination of reproductive speed traits (generation length and clutch size) and specialisation traits (pelagic specialism, diet and habitat breadth) drive the greatest dissimilarity between threat types (Table 2.4). Specifically, we find the of reproductive speed and pelagic specialism traits drive the greatest dissimilarity between direct and habitat threats. Diet and reproductive speed traits explain the greatest dissimilarity between direct threats and no threats. Finally, diet and habitat breadth explain the greatest dissimilarity between habitat threats and no threats.

Through generalising the directionality of important trait contributors between each threat (Table 2.4), we find seabird species with similar ecological roles are responding similarly to human pressures (Fig. 2.4). Species with slow reproductive speeds, specialisation traits (pelagic specialism) and omnivorous diets are at greater risk from direct threats. Direct threats target all families of seabird, but most are tubenose seabirds (albatross, shearwaters and petrels). Habitat threats typically endanger those with fast reproductive speeds, specialisation traits (small habitat breadth) and omnivorous diets. These species are typically gulls and terns, yet habitat threats target all families of seabird. Species with no threats, which are primarily gulls, have the fastest reproductive speeds, generalist traits (non-pelagic specialism, larger habitat breadth) and invertebrate diets.

Table 2.4 SIMPER summary of top five traits contributing to the Bray Curtis dissimilarity between threats. The proportion of species per trait is indicated as greater (+), or smaller (-) between each threat category.

Threat Contrast	Trait	Contribution (%)	Cumulative (%)	Direct	Habitat	No Threat
Direct vs. Habitat	Generation Length (S)	7.7	7.7	-	+	
	Clutch Size (S)	7.3	15.0	+	-	
	Non-pelagic Specialism	6.9	21.8	-	+	
	Pelagic Specialism	6.9	28.7	+	-	
	Generation Length (M)	6.2	34.9	-	+	
Direct vs. No Threats	Omnivore Diet	7.9	7.9	+		-
	Invertebrate Diet	7.3	15.2	-		+
	Generation Length (S)	7.2	22.4	-		+
	Clutch Size (S)	6.6	29.0	+		-
	Generation Length (M)	6.0	35.1	+		-
Habitat vs. No Threats	Omnivore Diet	10.1	10.1		+	-
	Invertebrate Diet	8.1	18.2		-	+
	Habitat Breadth (S)	7.1	25.2		+	-
	Habitat Breadth (M)	5.9	31.2		-	+
	Non-pelagic Specialism	5.8	37.0		-	+

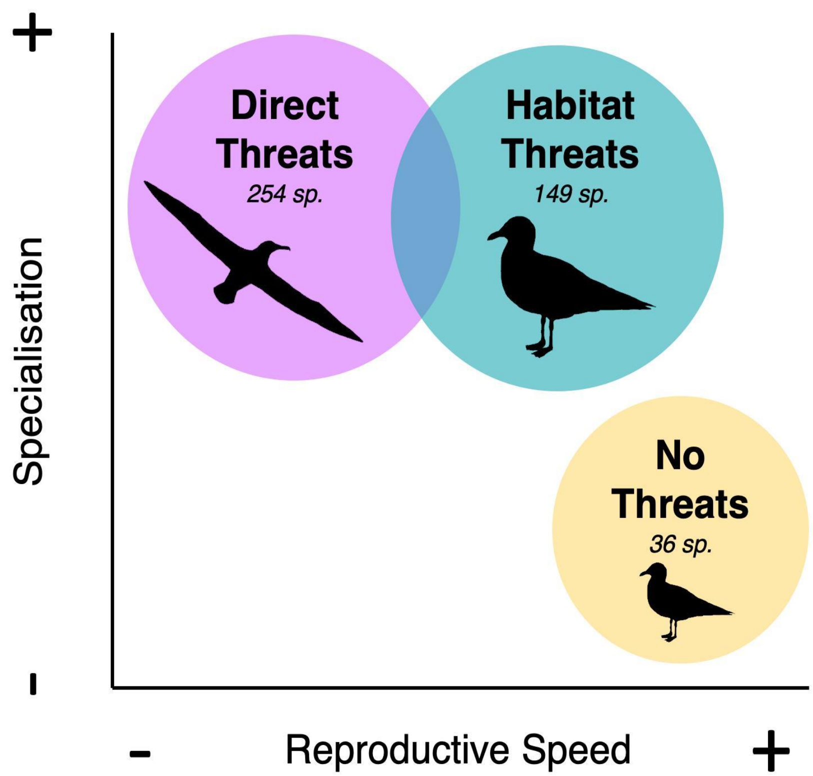


Figure 2.4 Generalised pattern of traits that predict vulnerability of seabirds to varying anthropogenic threats based on the results presented in Table 2.4. Silhouettes represent seabird families with high frequencies of species at risk to each threat type. Direct threats directly impact the survival and fecundity of seabirds, while habitat threats modify or destroy habitats. Reproductive speed is the trade-off between clutch size and generation length. Specialisation encompasses pelagic specialism and habitat breadth.

2.4.5 Sensitivity

We find that our results and conclusions were comparable between the imputed and non-imputed datasets (Appendix A). However, the body mass of globally threatened species was 0.33x greater [95% ci: 0.08, 0.58] than non-threatened species, a significant difference (Mann-Whitney U test; W = 10160, $p = 0.007$), when using the non-imputed dataset.

2.5 Discussion

We reveal both globally threatened and non-threatened seabirds occupy different regions of trait space. Specifically, globally threatened species share a distinct subset of similar traits that are associated with a higher risk of extinction. Therefore, the loss of threatened species, such as wide-ranging albatross and shearwaters, may have direct implications for ecosystem functioning such as trophic regulation, nutrient transportation and community shaping (Graham et al., 2018; Tavares et al., 2019). We further find non-threatened species have relatively unique ecological strategies and little redundancy. Consequently, non-threatened species may have less insurance to buffer against ecosystem functioning declines should they become threatened in the future. We must therefore prioritise the conservation of both threat groups, but with different approaches to avoid potential changes in ecosystem functioning and stability. Globally threatened species would benefit from targeted conservation interventions, whereas non-threatened species need long-term monitoring of populations and their environment (Hebert et al., 2020).

We find a number of traits emerge with strong association to extinction risk and different threatening processes. Overall, anthropogenic pressures may be selecting against slow-lived and specialised species e.g., albatross and petrels, in favour of fast-lived and wide-ranging generalist e.g., gulls and terns. This agrees with the patterns of other birds and mammals (Davidson et al., 2009; Peñaranda & Simonetti, 2015; Cooke, Eigenbrod & Bates, 2019). However, in contrast to numerous studies (Cardillo et al., 2005; Ripple et al., 2017; Cooke, Eigenbrod & Bates, 2019), we find no difference in the body mass of globally and non-threatened species. Therefore, threats are indiscriminate across seabirds from the largest (the wandering albatross, 7000 g) to the smallest seabird (the European storm-petrel, 25 g). Potential explanations could be that major threats to seabirds are not size dependent. For example, invasive species on a breeding island would consume all species' eggs, and all sizes of seabirds are attracted to fishing vessels. Moreover, large seabirds are less targeted for hunting in comparison to mammals, e.g., game mammals. Alternatively, this pattern could be an artefact of our imputation approach because body mass was significantly different between globally and non-threatened species when using the non-imputed data.

Traits explaining the greatest difference between direct threats and other threats were slow reproductive speeds and pelagic specialism, supporting recent findings (Gonzalez-Suarez, Gomez & Revilla, 2013). Here, direct threats encompass invasive species and bycatch, which are the top two threats facing seabirds worldwide (Dias et al., 2019), in addition to human disturbance. Most species at risk to direct threats are tubenose seabirds (albatross, petrels, shearwaters). Tubenoses are highly pelagic species that depend on the ocean for foraging. Therefore, tubenoses often strongly overlap with fishing vessels (Chapter 3; Clay et al., 2019) and opportunistically scavenge fisheries discards. In this process, birds are caught on baited hooks and drowned, or entanglement in nets and collide with cables which results in high mortality. Consequently, an estimated 320,000 seabirds die annually in longline fleets alone (Anderson et al., 2011). Tubenose seabirds are further strongly impacted by invasive species (e.g., rats and cats) and human disturbance at breeding colonies. These seabirds lay a single egg per season, therefore their populations have a lower capacity to compensate for bycatch mortality and poor reproductive success due to invasive species and human disturbance.

We find species at risk to habitat threats have the smallest habitat breadths, and slower reproductive speeds than species with no threats. This finding corroborates previous studies which identify habitat specialisation increases species' vulnerability and limits their capacity to adapt to environmental change (Gonzalez-Suarez, Gomez & Revilla, 2013; Peñaranda & Simonetti, 2015). Habitat threats particularly target species such as cormorants and gulls. Coastal and wetland habitats are vital for these seabirds during wintering and breeding, yet they are being modified and destroyed by tourism and urbanisation.

Identifying traits most associated with threats can lead to more informed and effective conservation strategies. Species at risk to direct threats need targeted conservation interventions through bycatch mitigation and invasive species eradication to protect highly pelagic species with slow reproductive speeds. These initiatives are beginning to show great promise. For example, implementing bird deterrents in a South African trawl fishery reduced albatross deaths by 95% between 2004 to 2010 (Maree et al., 2014). Furthermore, eradicating rats from breeding colonies has dramatically recovered seabird populations (Veitch et al., 2019), and restored ecosystem functions such as nutrient transportation to soil and plants (Wardle et al., 2009, 2012; Jones, 2010). Habitat breadth is strongly related to threat status, therefore many species will benefit from habitat conservation and marine spatial planning. For example, through designating protected areas at sea to conserve important seabird hotspots, movement pathways and foraging areas (Ronconi et al., 2012; D'Aloia et al., 2019). At breeding sites, closing colony visitation during the breeding season and establishing buffer zones for land, water, and air could eliminate disturbance and nest abandonment.

Here we use the IUCN database to identify the traits most associated with different threats. However, the collation of IUCN threats, via expert opinion, is subjective and can contain bias (Hayward, 2009), therefore threats may be unreported or overreported. Furthermore, rare or understudied species, for example the Critically Endangered magenta petrel (*Pterodroma magenta*) with fewer than 100 mature individuals, likely have fewer known threats than highly studied species such as the Atlantic puffin (*Fratercula arctica*). Further studies that couple spatial patterns of extrinsic threats with intrinsic traits could offer valuable insight into species vulnerabilities to anthropogenic threats, and ultimately help inform effective management and conservation at local and global scales (Chapter 3).

In conclusion, we expand our understanding of extinction risk drivers in seabirds through a trait-based approach. Here we highlight the need to conserve both globally and non-threatened species in order to conserve the diversity of ecological strategies and associated ecosystem functions. We suggest traits be coupled with spatial patterns of extrinsic threats to advance conservation management strategies.

2.6 Co-authorship Statement

- I, **Cerren Richards**, designed and identified the research questions, analyzed the data, prepared the figures and tables, and authored the manuscript.
- **Robert S.C. Cooke** contributed body mass, clutch size, habitat breadth and diet guild trait data for 281 seabirds, assisted with coding the random forest imputation approach in R and preparing its description for the manuscript (section 2.3.2).
- **Amanda E. Bates** assisted with the conceptualization of the manuscript.

Chapter 3 Using species' traits to quantify seabird bycatch vulnerability and predict conservation gains

3.1 Abstract

Fisheries bycatch, the incidental mortality of non-target species, is a profound threat to seabirds worldwide. Reducing bycatch is crucial to reduce declines of species' populations and consequent changes in ocean trophic dynamics and ecosystem functioning. Therefore, core fisheries management and conservation goals are to identify the most vulnerable species, and quantify the success of possible mitigation strategies. Here we combine species' traits and distribution ranges for 341 seabirds with a spatially resolved gear-specific fishing effort dataset to (1) understand spatial variation in seabird community traits; (2) quantify species vulnerability based on their exposure, sensitivity and adaptive capacity to longline, trawl and purse seine bycatch; and (3) predict whether mitigating bycatch has the potential to conserve community traits. We find distinct spatial variation in the community weighted mean of four seabird traits, and our analysis suggests that successful bycatch mitigation may prevent significant shifts in the traits of seabird communities across the globe. We identify the species most vulnerable to gear-specific bycatch, and classify all 341 seabirds into five vulnerability classes to aid conservation decision-making. Species classified as most vulnerable were typically albatross, shearwaters, gulls, and terns (e.g. Herring Gull (*Larus argentatus*) and Glaucus-Winged Gull (*Larus glaucescens*)), while least vulnerable were gulls, terns, and cormorants (e.g. White Tern (*Gygis alba*) and Brown Noddy (*Anous stolidus*)). We further find species listed as threatened from bycatch by the International Union for Conservation of Nature (IUCN) are distributed throughout the five vulnerability classes categorized here. This could suggest that a number of species threatened from bycatch are going undetected and unreported to the IUCN.

3.2 Introduction

Global fishing effort and capacity have more than doubled since 1950 (Rousseau et al., 2019) with direct and indirect ecological consequences for marine fauna (Lewison et al., 2004; Senko et al., 2014; Komoroske & Lewison, 2015). Fisheries bycatch, the incidental mortality of non-target species, is a serious threat to many marine species, from fish and crustaceans to megafauna including sea turtles, marine mammals, and seabirds (Alverson et al., 1994; Lewison et al., 2004). Indeed, bycatch is a major driver of seabird population declines worldwide (Anderson et al., 2011; Croxall et al., 2012; Hedd et al., 2016; Dias et al., 2019). For instance, bycatch has driven populations of three South Georgian albatross species to plummet by 40-60 % over 35 years (Pardo et al., 2017). Reducing fisheries bycatch is, therefore, critical to prevent direct declines of seabird populations and indirect loss of ecosystem functions, such as nutrient transportation, provided by seabirds (Komoroske & Lewison, 2015). Thus, key goals for successful fisheries management and conservation are to identify vulnerable non-target species and develop mitigation strategies that reduce the negative impact of fisheries activities on these species. Yet, these goals pose global challenges because seabirds are wide ranging and encounter fishing activities in various national and international waters at different stages of their life history (Komoroske & Lewison, 2015). Better understanding of the factors affecting vulnerability of species to bycatch is an essential step towards predicting species at risk and reaching these important goals.

While seabird bycatch is widespread, a global quantification of seabird vulnerability to fisheries bycatch in multiple gear types is lacking because bycatch data are scarce (Zhou, Jiao & Browder, 2019). However, many seabird species are attracted to fishing vessels to opportunistically scavenge fisheries discards. Yet, the nature of the gear type determines the risk to seabirds. On longliners, seabirds are caught on baited hooks and drowned, while on trawlers and purse seines, they tangle in nets and collide with cables when attracted to the catch. It is estimated that up to 1 bird is caught for every 1000 hooks across longline fisheries worldwide, but only recently has the threat posed by trawl fisheries become apparent (Bartle, 1991; Weimerskirch, Capdeville & Duhamel, 2000;

Sullivan, Reid & Bugoni, 2006; Anderson et al., 2011). Furthermore, purse seine fisheries are globally distributed but little is known about their overall impacts on non-target species (Suazo et al., 2017).

A trait-based vulnerability assessment may be a particularly valuable tool to identify seabird species most vulnerable to gear-specific bycatch, and could reveal seabirds at risk that are going undetected by vessel surveys. Traits are attributes of organisms, measured at the individual level without reference to the environment (Violle et al., 2007; Gallagher et al., 2020). Selecting ecologically meaningful and interpretable traits, relating to life-history, morphology and behaviour, can relate to species' vulnerabilities (Zhou, Jiao & Browder, 2019). Seabirds are an exceptionally well-studied group compared to other marine species because these birds require terrestrial landmasses to breed, and therefore can be monitored throughout the breeding season. Furthermore, recent technological advances through miniaturization of biologging devices have revealed seabird foraging behaviours and distributions at sea and during the winter (Richards et al., 2019). Thus, detailed information is available on the life history, behavioural and ecological traits of seabirds for predictive trait-based analyses.

A species' vulnerability to bycatch is determined by both extrinsic (e.g., threats) and intrinsic (e.g., traits) factors. Specifically, such factors include the interplay between a species' exposure, sensitivity, and capacity to adapt in response to bycatch (Foden et al., 2013; Potter, Crane & Hargrove, 2017; Butt & Gallagher, 2018). Firstly, exposure describes the extent to which species' ranges overlap with fishing activity. For example, wide-ranging pelagic foragers, such as albatross, overlap with a variety of gears and fleets throughout their lives (Clay et al., 2019). Secondly, sensitivity traits represent a species' likelihood of bycatch mortality when it interacts with fisheries. For example, large seabirds have a greater risk of bycatch mortality than smaller seabirds (Zhou, Jiao & Browder, 2019). In the case of seabirds, bycatch could be detrimental to endangered species with fewer than 100 documented mature individuals such as the Chinese crested tern (*Thalasseus bernsteini*) and magenta petrel (*Pterodroma magenta*) (IUCN, 2020).

Finally, adaptive capacity traits describe the ability for populations to adapt and recover from bycatch mortalities. For example, bycatch will have a greater impact on seabirds with slow reproductive rates, such as albatross and auks, which lay a single egg per season and reach sexual maturity after five to ten years.

Trait-based approaches may further offer a valuable tool set in which to evaluate conservation successes and highlight regions where conservation strategies will provide the most gains. Simple, innovative, and inexpensive mitigation solutions have substantially reduced bycatch across gear types and species, by up to 95% (Croxall, 2008; Maree et al., 2014). These solutions include gear modifications that increase net visibility and deter species with scaring lines, and management actions including time-area closures that prohibit fishing in an area or at specific times (Senko et al., 2014). However, it remains an open question how and where mitigating bycatch at a global scale may conserve seabird traits and the ecological strategies that traits represent (Gallagher et al., 2020). When traits relate to function, they can be used to infer species' contributions to ecosystem functioning (Gallagher et al., 2020). For example, seabirds are often top predators, consequently their diet and foraging strategy can relate to functions such as trophic regulation of populations and nutrient storage (Tavares et al., 2019). Thus, trait analyses may offer opportunities to highlight important oceanic regions susceptible to the greatest loss of ecosystem functioning without bycatch mitigation measures.

Here we combine a dataset of five traits across 341 seabird species with global range maps and a spatially resolved gear-specific fishing dataset to: (1) quantify seabird vulnerability to bycatch using a hierarchical prioritization framework that integrates three dimensions of vulnerability (exposure, sensitivity, and adaptive capacity); (2) map and describe the spatial variation in community traits; and (3) test whether mitigating fisheries bycatch may prevent significant shifts in traits of seabird communities and loss of ecological strategies. Collectively, these objectives allow us to identify the species most vulnerable to gear-specific bycatch, and highlight on the oceanic regions susceptible to the greatest loss of ecosystem functioning without bycatch mitigation measures. Finally, we discuss our findings within the context of monitoring, management and conservation.

3.3 Methods

3.3.1 Vulnerability Framework

To identify species most vulnerable to gear-specific bycatch, we modified a hierarchical prioritisation framework (Foden et al., 2013; Potter, Crane & Hargrove, 2017; Fig. 3.1). The framework integrates three dimensions of bycatch vulnerability; (1) **exposure** which captures the potential extent and magnitude of fishing activity experienced by species; (2) **sensitivity** which encompasses a species' traits that reflect propensity to interact with and be affected by different fishing gear types; and (3) **adaptive capacity** which reflects the capacity of populations to recover from bycatch mortalities. Each dimension encompasses a set of vulnerability attributes (Size, Feeding, Range, Magnitude, Population, and Rarity) that in turn are represented by species' traits (Fig. 3.1).

3.3.2 Assessing sensitivity and adaptive capacity to bycatch

We selected two traits (Fig. 3.1 - Box C) to infer the framework's sensitivity dimension: body mass, the median mass in grams; and foraging guild, the dominant foraging strategy of the species (Diver, Surface Feeder, Ground Feeder, Generalist). We used three traits (Fig. 3.1 - Box D) to quantify the adaptive capacity dimension: generation length, the age at which a species produces offspring in years; clutch size, the number of eggs per clutch; and IUCN Red List category, which categorises species from low extinction risk (Least Concern, Near Threatened) to high extinction risk (Critically Endangered, Endangered, Vulnerable). Traits were compiled from four main sources: body mass and clutch size data were extracted from Cooke, Bates & Eigenbrod (2019); generation length from BirdLife International (Bird et al., 2020); foraging guild from Wilman et al. (2014); and IUCN category from the IUCN Red List (IUCN, 2020).

We log_{10} transformed body mass, habitat breadth, and generation length traits to make the trait units more understandable for the analyses. All traits had >80% coverage for our list of 341 seabird species. To achieve complete trait coverage, we imputed missing traits with random forest regression trees, based on the ecological and phylogenetic relationships between species (Stekhoven & Bühlmann, 2012). We generated 15 trait datasets to account for imputation uncertainty, and took the mean trait values across the 15 datasets for subsequent analyses. For full details on the imputation approach see Chapter 2.

3.3.3 Assessing exposure to bycatch

To estimate the framework's exposure dimension, we quantified (1) overlap with fisheries activities - the extent to which species' distributions overlap with spatially-resolved gear-specific fishing and (2) fishing intensity - the intensity of fishing within the overlap regions (Fig. 3.1 – Box B).

First, we extracted distribution polygons for 341 seabirds from BirdLife International data zone (BirdLife International, 2017). Bird distribution data are available upon request from datazone.birdlife.org/species/requestdis. These spatial polygons represent the coarse distributions that species likely occupy, and are presently the best available data for the ranges of all seabirds. We subset the spatial data to only retain the extant, native, resident, breeding season and non-breeding season polygons. We created a 1° resolution global presence-absence matrix based on the seabird distribution polygons using the package 'letsR' and function *lets.presab* (Vilela & Villalobos, 2015) for further analyses.

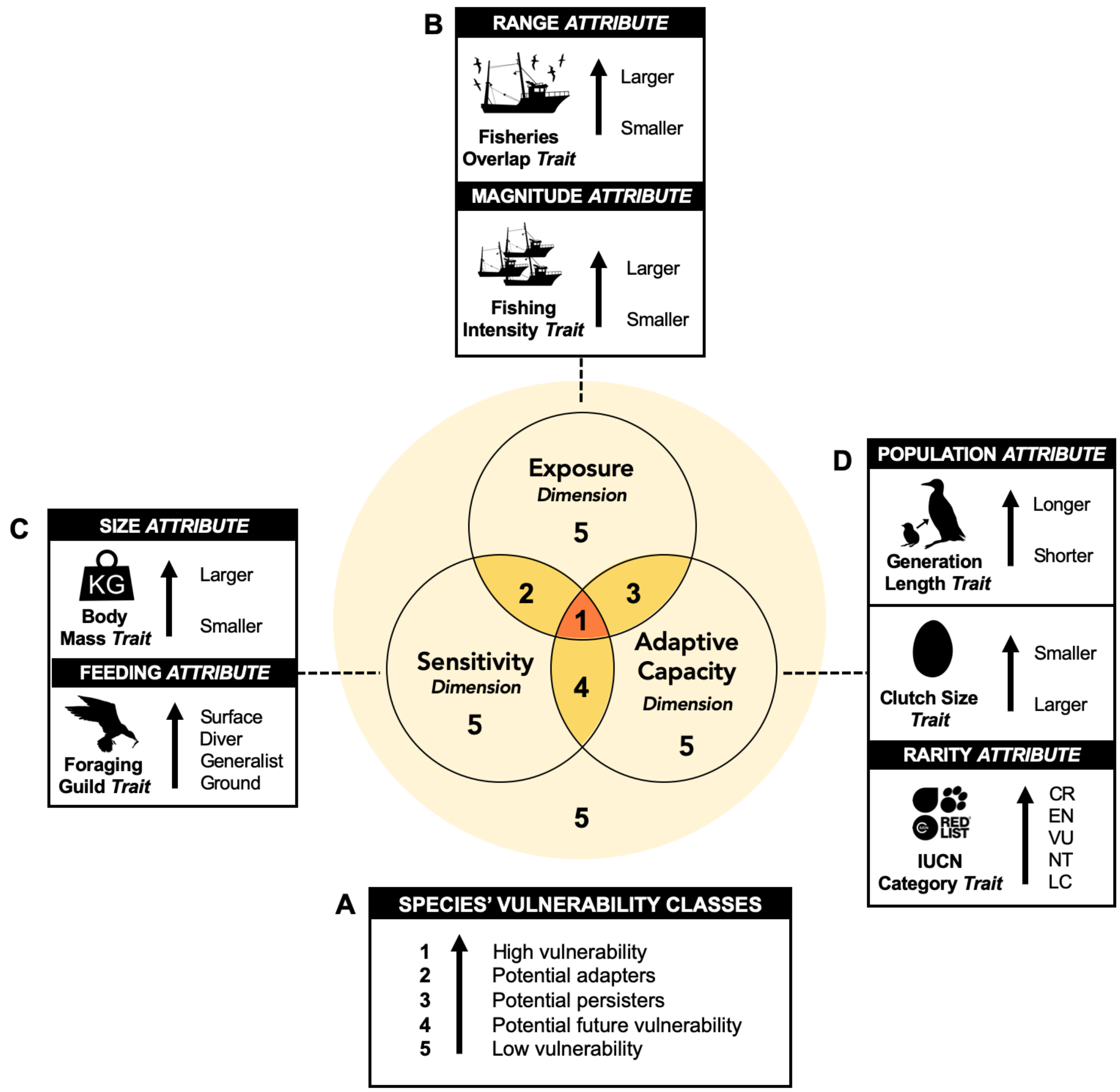


Figure 3.1 *Framework to quantify species' vulnerability to bycatch. The combination of three dimensions: exposure, sensitivity and adaptive capacity, characterise five distinct species' vulnerability classes (Box A). Each has implications for conservation prioritisation and strategic planning (Foden et al., 2013). Seven traits associated with five overarching vulnerability attributes (Boxes B-D: Size, Feeding, Range, Magnitude, Population, and Rarity) are used to quantify each vulnerability class. Black arrows indicate the direction of increased vulnerability. Modified from Foden et al. (2013) and Potter, Crane & Hargrove (2017).*

Second, we downloaded fine scale spatio-temporal fishing effort data from Global Fishing Watch (globalfishingwatch.org). Global Fishing Watch analyses fishing activity data using the Automatic Identification System (AIS). While AIS is a safety device used onboard vessels to avoid collisions, it also transmits data about a vessel's identity, type, location, speed and directions (Kroodsma et al., 2018). These data are processed using convolutional neural networks to characterise fishing vessels, gear types and periods of fishing activity with 94–97% accuracy when compared with labelled data (Kroodsma et al., 2018; Guiet et al., 2019). AIS is mandated on vessels larger than 300 gross tonnes travelling in international waters (International Maritime Organization) and is estimated to cover over 50% of nearshore and up to 80% of high sea fishing effort (Sala et al., 2018). We extracted the daily fishing activity data for longlines, trawls and purse seines from Global Fishing Watch. These three gear types were selected because they (1) have the highest quality and coverage within the Global Fishing Watch dataset, (2) cause the greatest seabird bycatch mortalities (longlines and trawls), and (3) may offer new insights into the unknown impact of purse seine bycatch on seabird species. For each gear type, fishing effort was summed per 1° global grid cell between 2015 and 2018. While estimated 400,000 seabird mortalities are caused in gill net fisheries annually (Žydelis, Small & French, 2013), we excluded this gear type from our analyses because it has poor coverage within the Global Fishing Watch dataset.

Finally, to ensure consistency between the species' distribution and gear-specific fishing activity layers, we re-projected all spatial data to a raster format with the same coordinate reference system (WGS84), resolution (1° x 1° global grid cells) and extent (± 180°, ± 90°). To achieve this, we used the package 'raster' and function *rasterize* (Hijmans, 2019). We calculated spatial "overlap with fisheries" as the percentage of cells overlapping between species ranges and each gear-specific fishing activity. "Fishing intensity" is the sum of all fishing hours in the overlapping cells.

3.3.4 Calculating bycatch vulnerability

Each trait, attribute and dimension were scored between 0 - 1, with 1 indicating the greatest vulnerability to bycatch (Potter, Crane & Hargrove, 2017). This was achieved through a stepwise process. First, all continuous traits from the vulnerability dimensions (*body mass, clutch size, generation length, overlap with fisheries, and fishing intensity*) were broken into categories using the Sturges algorithm which bins the traits based on their sample size and distribution of values (Sturges, 1926). All trait categories were then scored from high to low with ordinal variables based on increased vulnerability to bycatch (Table S1). To ensure the prioritisation analysis predictably weights the criteria (Mace, Possingham & Leader-Williams, 2007), all scores were scaled between zero and one and weighted by the frequency of trait occurrence (Potter, Crane & Hargrove, 2017).

The following worked example represents the scoring and weighting steps for a trait with four categories:

Trait category 1 (lowest vulnerability) = 0
Trait category 2 = $(n_1 + n_2)/n_{total}$
Trait category 3 = $(n_1 + n_2 + n_3)/n_{total}$
Trait category 4 (highest vulnerability) = $(n_1 + n_2 + n_3 + n_4)/n_{total} = 1$

Where n is the number of species per trait category and n_{total} is the total number of species.

For example, foraging guild contains four categories: ground forager (category 1 = 13 species), generalist forager (category 2 = 63 species), diving forager (category 3 = 121 species) and surface forager (category 4 = 144 species), and n_{total} for this study is 341 species. Ground forager has the lowest conservation priority therefore is given a score of 0. All other foraging strategies are weighted proportionally based on the number of species within that category and the lower categories (Potter, Crane & Hargrove, 2017). Therefore, generalist forager's score is *(13 + 63) / 341= 0.22,* diving forager's score is

(13 + 63 + 121)/ 341 = 0.58 and surface foragers, with the greatest conservation priority, have a score of *(13 + 63 + 121 + 144)/ 341 =1.* These equations are run on each trait independently, and the number of trait categories varies between 3 to 5 per trait.

Finally, the attribute score is the mean across all traits within each attribute, and the dimension score is the mean across all attributes. Total vulnerability is the mean score across all three dimensions. A species with high bycatch vulnerability will have high scores in each of the sensitivity, adaptive capacity and exposure dimensions (Foden et al., 2013).

3.3.5 Calculating species vulnerability classes

We categorise species into vulnerability classes (Fig. 3.1A) based on a dimension score threshold of 55%. This threshold was decided by balancing between excluding all vulnerable species because thresholds were too high, and ensuring minimal species changes between threshold levels across all gear types (Appendix Fig. B.4). If all dimensions (exposure, sensitivity, and adaptive capacity) have a score greater or equal to 55%, species are highly vulnerable to bycatch, therefore, were classified into the "*high vulnerability*" class. If the scores of sensitivity and exposure were greater or equal to 55%, but adaptive capacity was less than 55%, species were considered to have high vulnerability with potential adaptive capacity, and were assigned to the "*potential adapters*" class. If the scores of adaptive capacity and exposure were greater or equal to 55%, but sensitivity was less than 55%, species were considered to have high vulnerability with potential to persist and were assigned to the "*potential persisters*" class. Species were classified into the "*potential future vulnerability*" class if the scores of adaptive capacity and sensitivity were greater or equal to 55%, but exposure was less than 55%. If all dimensions have a score less than 55%, or if only one dimension has a score greater or equal to 55%, species had low overall vulnerability and were assigned to the "*low vulnerability*" class.

This approach is repeated for the three gear types (longline, trawl and purse seine). Thus, all species receive vulnerability scores and classes associated with each gear type. We further compare how the species listed as threatened from bycatch by the IUCN are distributed across all five vulnerability classes.

3.3.6 Community Weighted Mean

To map and describe the global distribution of traits, we calculated the community weighted mean (CWM) for each 1° grid cell with the function *functcomp*, package 'FD' (Laliberté & Legendre, 2010; Laliberté, Legendre & Shipley, 2014). For continuous data, CWM is the mean trait value of all species present in each 1º grid cell and for categorical data, CWM is the most dominant class per trait within each 1º grid cell. Community weighted means characterises the typical characteristics within a set of species by combining information on species' traits and distributions (Duarte et al., 2017). Here we focus on body mass, clutch size, generation length and foraging guild traits, and use the presence-absence matrix to identify the community composition of each 1° grid cell. We do not weight the CWM by species relative abundances because these data were not available. All land was removed from the presence-absence matrix using the *wrld_simpl* polygon from the package 'maptools' (Bivand & Lewin-Koh, 2018) and function *lets.pamcrop* from the package 'letsR' (Vilela & Villalobos, 2015).

3.3.7 Trait shifts

To quantify the extent to which mitigating fisheries bycatch will prevent shifts in traits of seabird communities, we selected different approaches for the continuous and categorical traits. For the continuous traits, we removed 134 species listed as threatened from bycatch by the IUCN from our total species list and recalculated the community weighted mean of each trait. For each 1º grid cell, the percentage deviation in CWM ($\text{Deviation}_{\text{Continuous}}$) was calculated with the following equation:

$$\text{Deviation}_{\text{Continuous}} = (CWM_{Bycatch} - CWM_{Total} / CWM_{Total}) \times 100$$

Where $CWM_{Bycatch}$ is the community weighted mean following removal of species threatened from bycatch and CWM_{Total} is the community weighted mean of the total species list.

To quantify the community shift in foraging guild, a categorical trait, we calculated the proportion of each category (*surface, diving, generalist and ground*) per 1º grid cell, then recalculated the proportion deviation from the total following the removal of species threatened from bycatch. The deviation in foraging category per 1º grid cell ($\text{Deviation}_{\text{Categorical}}$) was calculated with the following equation:

$$\text{Deviation}_{\text{Categorical}} = \text{Proportion}_{\text{Bycatch}} - \text{Proportion}_{\text{Total}}$$

For each foraging guild category, $\text{Proportion}_{\text{Bycatch}}$ represents its proportion within the community following removal of species threatened from bycatch. $\text{Proportion}_{\text{Total}}$ is its proportion within the whole community. To further explain the trends in foraging guild shifts, we quantify the redundancy of foraging guild categories and loss of species per foraging guild within each community. Redundancy was calculated as the number of species which were represented in each foraging guild category, within each grid cell. Species loss was the number of species identified as threatened from bycatch by the IUCN for each foraging guild, within each grid cell.

To describe the spatial trends in trait shifts across latitude, we fitted general additive models (GAM) using the package 'mgcv' and function *gam* (Wood, 2017). For each trait, latitude was included as the predictor and $\text{Deviation}_{\text{Continuous}}$ or $\text{Deviation}_{\text{Categorical}}$ as the response. All analyses were complete in R version 3.5.0.

To compare whether our community weighted mean results and conclusions were comparable between the imputed and non-imputed datasets, we ran our analyses with and without the imputed data.

3.4 Results

3.4.1 Spatial variation in community traits

We find large spatial variation in the community weighted mean (CWM) of clutch size, body mass, generation length, and foraging guild traits across the globe. Species with the largest clutch sizes are distributed along coastlines, particularly in the Northern Hemisphere. In contrast, species with the smallest clutch sizes are highly pelagic and distributed across all oceans (Fig. 3.2A). The CWM for body mass is more evenly distributed, with the heaviest species being located in the Southern Ocean (Fig. 3.2B). Species with small body masses are distributed between 30°N and 30°S e.g. Storm-petrels and Dovekies. Generation length is also evenly distributed globally (Fig. 3.2C). Species with the longest generation lengths are concentrated in the Southern Ocean, whilst the shortest generation lengths are along coastlines. For foraging guild (Fig. 3.2D), surface foragers typically dominate most oceans below 50°N whilst divers are the most dominant above 50°N and along the coast of Atlantic Central America, and Oceania. Generalists are concentrated around the coasts of Europe (Mediterranean Sea, Black Sea, Baltic Sea, North Sea) and ground foragers dominate in the high Arctic e.g. Ivory Gull.

3.4.2 Mitigating fisheries bycatch

Combined, longline, trawl, and purse seine fisheries accounted for 100,000,000 hours of fishing effort between 2015-2018. Successful bycatch mitigation has the potential to prevent shifts in the traits of seabird communities across the globe (Fig. 3.2 & 3.3). Removal of bycatch threats could prevent the increase in clutch size above 50°S, and decrease in clutch size below 50°S (Fig. 3.2E & 3.3A). Furthermore, the global shift in CWM to species with shorter generation lengths and smaller body masses could be avoided (Fig. 3.2F-G & 3.3B-C). This is trend particularly prominent between 30° and 70° in both hemispheres.

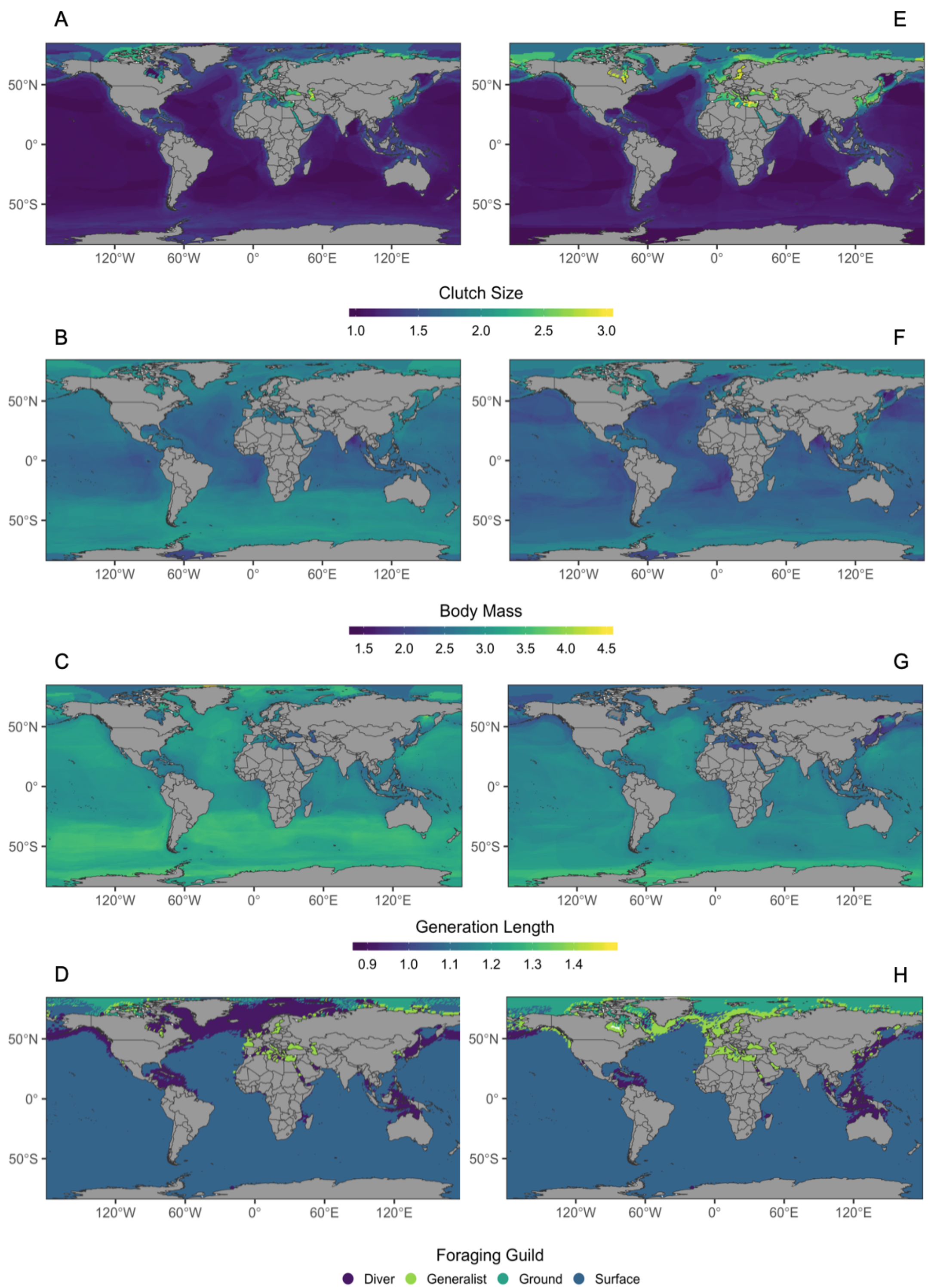


Figure 3.2 Spatial conservation of traits through bycatch mitigation. A-D: present day community weighted mean (CWM) of four traits based on the distributions of 341 seabird

species. E-H: community weighted mean of four traits following the removal of 134 species threatened from bycatch. Therefore, the difference represents the shifts in traits that may be prevented through successfully mitigating seabird bycatch. For continuous data, CWM is the mean trait value of all species present in each 1° grid cell and for categorical data, CWM is the most dominant class per trait within each 1° grid cell. Body mass and generation length traits are log_{10} transformed.

Mitigating bycatch could further prevent the shifts of foraging guild dominance from diving and surface foragers to generalist and ground foragers above 40°N (Fig. 3.2H & 3.4A-D). Below 40°N, we find surface foragers may remain the dominant foraging guild without bycatch intervention (Fig. 3.2H), but their proportion within the community could increase (Fig. 3.4A). The proportion of divers within the community may also increase slightly between 40°N and 50°S, but decrease below 50°S, generalist foragers could decrease below 40°N and ground foragers may remain relatively stable (Fig. 3.4B-D).

In addition to preventing shifts in the proportion of each foraging guild within the community, bycatch mitigation may further prevent the loss of species across all foraging strategies and latitudes (Fig. 3.4E-H). Surface foragers could receive the greatest protections since up to 20 species per grid cell might not be impacted by bycatch mortality in the Southern Hemisphere (Fig. 3.4E). Furthermore, a maximum of 11 divers, eight generalists and one ground forager per grid cell may be less likely to go locally extinct due to fishing practices (Fig. 3.4F-H).

Redundancy, the number of species with similar traits within each 1° grid cell, is highest for surface foragers (maximum 40 species per cell; Fig 3.4I) and lowest for ground foragers (maximum five species per cell; Fig 3.4L). Diving and generalist foragers have similar redundancy with a maximum of 18 and 16 species per cell, respectively (Fig 3.4J-K).

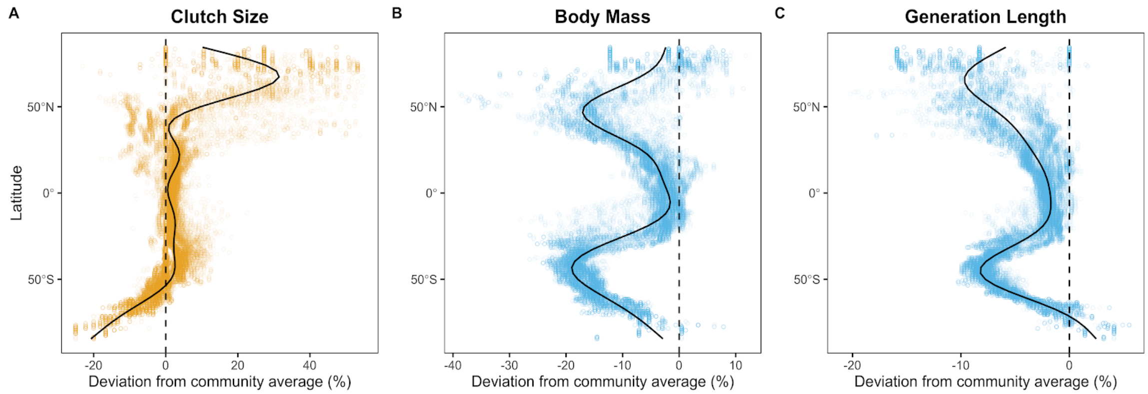


Figure 3.3 Shift in community weighted mean (CWM) across latitude following removal of 134 species threatened from bycatch. Each data point is community weighted mean within a 1º grid cell. Dashed zero line represents the community weighted mean of the total species list (341 species). Solid black lines are fitted generalized additive models (GAM) describing the spatial trends in trait shifts across latitude. Orange represents a significant overall positive shift from the GAM output, and blue a significant overall negative shift in the CWM following removal of species threatened from bycatch. Figures were cropped to remove extreme outliers identified by Rosner's Tests.

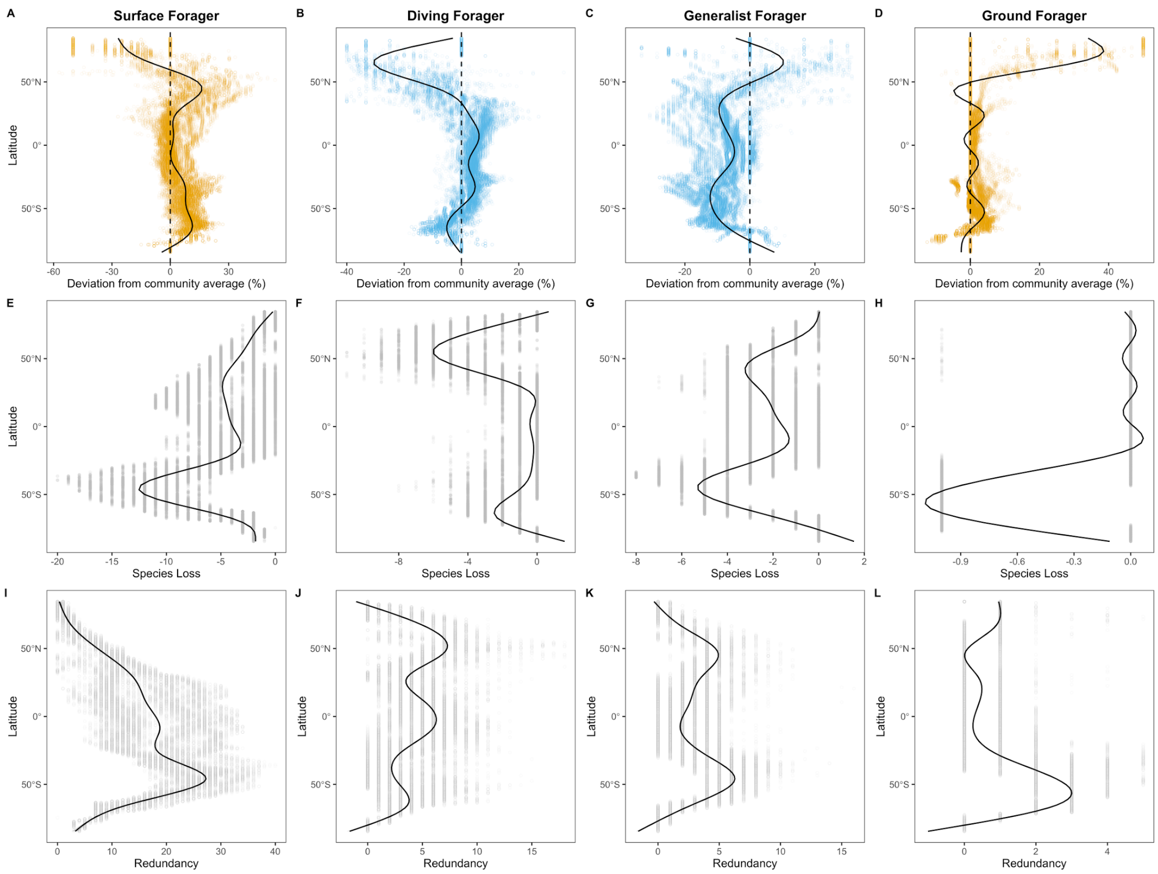


Figure 3.4 Latitudinal community shift in foraging guild proportion (A-D) and species loss (E-H) following removal of 134 species threatened from bycatch, and the redundancy of each foraging guild (I-L). Dashed zero line represents the proportion of each category for the total species list (341 species). Solid black lines are fitted generalized additive models (GAM) describing the spatial trends in trait shifts across latitude. Orange represents a significant overall positive shift from the GAM output, and blue a significant overall negative shift. Species loss (E-H) is the number of species lost per 1º grid cell following the removal of 134 species threatened from bycatch. Redundancy (I-L) is the number of species represented in each foraging guild category, within each 1º grid cell. A-D were cropped to remove extreme outliers identified by Rosner's Tests.

3.4.3 Sensitivity

We find that our results and conclusions were comparable between the imputed and non-imputed datasets (Appendix B).

3.4.4 Species vulnerability to bycatch

Species falling into the *high vulnerability* class have high scores across all three dimensions, and the greatest mean vulnerability score for all gear types (longline = 0.79, trawl = 0.78; purse seine = 0.68; Table 3.1). This class encompasses 37 species for longline bycatch, 12 species for trawl bycatch, and 15 species for purse seine bycatch vulnerability. Of these species, the most vulnerable were predominantly tubenose seabirds (albatross, petrels and shearwaters), gulls, and terns e.g. White Tern (*Gygis alba*) and Brown Noddy (*Anous stolidus*) (Table 3.2; Table B.1-3).

Species within the *potential adapters* class have high scores for sensitivity and exposure dimensions, but do have adaptive capacity due to low scores in this dimension (Table 3.1). The *potential adapters* class has a mean vulnerability of 0.64 for trawl bycatch (n = 10 sp.), and 0.62 for purse seines (n = 9 sp.). No species fell into this class for longline bycatch. The most common species within the *potential adapters* class were gulls and cormorants (Table B.1-3).

The *potential persisters* class encompasses species with a low sensitivity score, but high adaptive capacity and exposure scores (Table 3.1). For longlines, the mean vulnerability score was 0.68 (n = 7 sp.), for trawls was 0.63 (n = 6 sp.), and for purse seine was 0.62 (n = 4 sp.). Species in this class were typically tubenose seabirds, gulls, and terns (Table B.1-3).

The greatest number of species fell into the *potential future vulnerability* class for trawls (n = 160 sp.) and purse seines (n = 157 sp.), and second greatest for longlines (n = 135 sp.). This class has high scores for sensitivity and adaptive capacity, but a low score for exposure (Table 3.1). The mean vulnerability score in the *potential future vulnerability* class was 0.61 for longlines, 0.55 for trawls and 0.56 for purse seines. Species in the *potential future vulnerability* class covered all seabird families except cormorants, however, the most common families in this class were tubenose seabirds, auks, gulls, and terns (Table B.1-3).

Finally, the *low vulnerability* class encompasses species with low scores across all dimensions, or a high score for only one dimension. This class had the lowest mean vulnerability score for all gear types (longline = 0.42, trawl = 0.44, and purse seine = 0.43; Table 3.1). The greatest number of species fell into the *low vulnerability* class for longline bycatch (n = 162 sp.), and the second greatest for trawls (n = 153 sp.) and purse seines (n = 156 sp.). Species categorised within the *low vulnerability* class were predominantly gulls, terns, and cormorants e.g. Herring Gull (*Larus argentatus*) and Glaucus-Winged Gull (*Larus glaucescens*) (Table B.1-3).

3.4.5 Comparison to IUCN

We find species listed as threatened from bycatch by the IUCN are distributed across all five vulnerability classes (Table 3.1 & 3.2). For all gear types, the greatest number of species fell into the *potential future vulnerability* class (longline – 80 sp., trawl – 75 sp., purse seine 73 sp.).

3.5 Discussion

Bycatch mortality is a pervasive threat to seabirds which is difficult to manage because events are rare and often undetected, leading to scarce data (Anderson et al., 2011; Suazo et al., 2017). Here we couple fine-scale fisheries data with species traits and distribution data to identify conservation priorities. We reveal successful bycatch mitigation has the potential to both protect species, which may in turn preserve ecosystem functions, particularly in the North Atlantic and Southern Oceans. Furthermore, we categorize species into vulnerability classes to facilitate conservation decision-making, and identify species so far overlooked by the IUCN.

Table 3.1 Number of species and mean dimension scores within each vulnerability class. Vulnerability class relates to the classes from Fig. 3.1. IUCN (n) indicates where the 134 species listed as threatened from bycatch by the International Union for Conservation of Nature (IUCN) fall out across the five vulnerability classes.

Gear Type	Vulnerability Class	Species (n)	IUCN (n)	Mean Sensitivity	Mean Adaptive	Mean Exposure	Mean Vulnerability
Longline	High Vulnerability	37	6	0.72	0.74	0.89	0.79
Longline	Potential Persisters	7	3	0.45	0.77	0.82	0.68
Longline	Potential Future Vulnerability	135	80	0.77	0.78	0.29	0.61
Longline	Low Vulnerability	162	45	0.52	0.54	0.19	0.42
Trawl	High Vulnerability	12	11	0.73	0.80	0.81	0.78
Trawl	Potential Adapters	10	5	0.66	0.44	0.80	0.64
Trawl	Potential Persisters	6	3	0.48	0.76	0.64	0.63
Trawl	Potential Future Vulnerability	160	75	0.76	0.77	0.14	0.56
Trawl	Low Vulnerability	153	40	0.51	0.55	0.27	0.44
Purse Seine	High Vulnerability	15	13	0.75	0.69	0.60	0.68
Purse Seine	Potential Adapters	9	3	0.71	0.45	0.71	0.62
Purse Seine	Potential Persisters	4	2	0.49	0.79	0.58	0.62
Purse Seine	Potential Future Vulnerability	157	73	0.76	0.78	0.15	0.56
Purse Seine	Low Vulnerability	156	43	0.50	0.55	0.23	0.43

Table 3.2 The top five most vulnerable species to gear-specific bycatch within vulnerability class one. Vulnerability is the mean of species' exposure, sensitivity, and adaptive capacity scores. Vulnerability class relates to the classes from Fig. 3.1, where "high vulnerability" represents species with high vulnerability, little adaptation or persistence potential. IUCN indicates whether the species is listed as threatened from bycatch by the International Union for Conservation of Nature (IUCN).

Gear Type	Species Name	Common Name	Order	IUCN	Sensitivity	Adaptive	Exposure	Vulnerability	Vulnerability Class
Longline	*Pterodroma cervicalis*	White-necked Petrel	Procellariiformes	✖ No	0.84	0.85	0.96	0.88	High Vulnerability
Longline	*Ardenna bulleri*	Buller's Shearwater	Procellariiformes	✔ Yes	0.84	0.89	0.90	0.88	High Vulnerability
Longline	*Pterodroma solandri*	Providence Petrel	Procellariiformes	✔ Yes	0.84	0.85	0.88	0.86	High Vulnerability
Longline	*Fregata minor*	Greater Frigatebird	Suliformes	✖ No	0.94	0.72	0.92	0.86	High Vulnerability
Longline	*Phoebastria nigripes*	Black-footed Albatross	Procellariiformes	✔ Yes	1.00	0.81	0.75	0.85	High Vulnerability
Trawl	*Fulmarus glacialis*	Northern Fulmar	Procellariiformes	✔ Yes	0.84	0.78	0.86	0.83	High Vulnerability
Trawl	*Puffinus mauretanicus*	Balearic Shearwater	Procellariiformes	✔ Yes	0.63	0.97	0.89	0.83	High Vulnerability
Trawl	*Phoebastria albatrus*	Short-tailed Albatross	Procellariiformes	✔ Yes	1.00	0.91	0.57	0.83	High Vulnerability
Trawl	*Fratercula arctica*	Atlantic Puffin	Charadriiformes	✔ Yes	0.63	0.91	0.89	0.81	High Vulnerability
Trawl	*Catharacta skua*	Great Skua	Charadriiformes	✔ Yes	0.94	0.61	0.86	0.81	High Vulnerability
Purse Seine	*Phoebastria albatrus*	Short-tailed Albatross	Procellariiformes	✔ Yes	1.00	0.91	0.57	0.83	High Vulnerability
Purse Seine	*Phoebastria nigripes*	Black-footed Albatross	Procellariiformes	✔ Yes	1.00	0.81	0.57	0.79	High Vulnerability
Purse Seine	*Phoebastria immutabilis*	Laysan Albatross	Procellariiformes	✔ Yes	0.94	0.84	0.55	0.78	High Vulnerability
Purse Seine	*Calonectris leucomelas*	Streaked Shearwater	Procellariiformes	✔ Yes	0.84	0.81	0.59	0.75	High Vulnerability
Purse Seine	*Cerorhinca monocerata*	Rhinoceros Auklet	Charadriiformes	✔ Yes	0.63	0.58	0.94	0.72	High Vulnerability

We find that mitigating bycatch could prevent species losses and shifts in traits of seabird communities. Specifically, changes in distribution of all foraging strategies, and shifts towards communities with smaller body masses may be prevented. Furthermore, it could prevent slight shifts from seabird K- to r-selected parental strategies. Bycatch mitigation may, therefore, directly benefit species and likely have important indirect benefits for sustaining ecosystem functioning, as mediated by species traits. For example, the conservation of foraging strategy traits may sustain trophic regulations and community structures, because, as top predators, seabirds influence marine food webs from the top down via direct and indirect pathways (Ripple et al., 2017). Moreover, body mass is strongly linked to nutrient transport and storage because large individuals hold and disperse large nutrient quantities (Anderson et al., 2011; Doughty et al., 2016; Tavares et al., 2019). Therefore, preventing shifts to smaller body masses could protect important zoogeochemical cycles of major elements worldwide (Speakman, 2005; Wing et al., 2014; Graham et al., 2018; Schmitz et al., 2018; Tavares et al., 2019). Our findings further suggest that conservation efforts in the Southern and North Atlantic Oceans may prevent the greatest changes in community traits and ecosystem functioning. Since our approach assumed the complete removal of species which are threatened from bycatch, i.e. the extinction of these species, future studies may consider investigating how reduced population sizes and changes in proportions of species abundance caused by bycatch could influence community traits. Furthermore, integrating our trait shift approach into future marine spatial planning frameworks (e.g. Augé et al., 2018) could provide new insights to support marine management and conservation.

We further recommend that shifts in trait data be carefully interpreted. Here we find that the proportion of surface foragers in the community would increase without conservation measures. This pattern is driven by trait redundancy because there are more surface foragers found throughout the open ocean compared to other foraging strategies. While redundancy acts like insurance to buffer against species loss, surface foragers are experiencing the greatest loss from bycatch pressures. Consequently, the conservation of surface foragers should be a priority.

A number of studies have documented the severity of bycatch impacts for seabirds (Dias et al., 2019), but a global quantification of seabird vulnerability to multiple gear types has previously been limited by lack of resources and the rarity of bycatch events (Anderson et al., 2011; Hedd et al., 2016; Suazo et al., 2017). Our flexible trait-based framework, coupled with the Global Fishing Watch database, allowed us to categorize all seabirds into vulnerability classes based on their exposure, sensitivity and adaptive capacity in response to gear-specific bycatch. While we were unable to quantify species vulnerability to gillnet fisheries because of poor coverage in the Global Fishing Watch dataset, we find species vulnerability varied between longlines, trawls and purse seines. The greatest number of species had high vulnerability to longline bycatch. These species were predominantly albatross, shearwaters and petrels. Our findings align with a number of other studies, which identify that an estimated 160,000 to 320,000 seabirds are annually killed on longlines, threatening the conservation status of many seabird species (Anderson et al., 2011; Dias et al., 2019).

The second greatest vulnerability scores across the three gear types were achieved for trawls. The most impacted species were typically North Atlantic seabirds such as the Northern Fulmar (*Fulmarus glacialis*) and Balearic Shearwater (*Puffinus mauretanicus*). Our vulnerability scores conform with studies that find fulmars, shearwaters and other tubenoses are strongly associated with trawl fisheries (Eich et al., 2016).

Finally, purse seines are globally distributed, but less is known about their impacts on non-target species (Suazo et al., 2017). A small number of studies have reported albatross, shearwaters, petrels and gulls seasonally interact with Australia and Argentinian purse seine fisheries (Seco Pon et al., 2012; Suazo et al., 2017). Yet, very few bycatch events have been recorded globally due to lack of bycatch survey programs (Suazo et al., 2017). Our framework provided new insights into species that may have the greatest vulnerability to purse seine bycatch. Specifically, our framework also identified albatross, shearwaters, petrels and gulls as being highly vulnerability to purse seine bycatch. However, the species reported in previous studies did not fall into our *high vulnerability* class. This difference may be because the vulnerability framework employed here does not incorporate seasonal variability in seabird and fisheries distributions. Future investigations could incorporate seasonal variability and further explore the extent different traits contribute to the vulnerability classifications.

We find species listed as threatened from bycatch by the IUCN are distributed throughout the five vulnerability classes. For example, an unexpected finding is that we identify the Balearic Shearwater (*Puffinus mauretanicus*) as having very high vulnerability to being bycaught in trawls (*high vulnerability* class, vulnerability score = 0.89). This shearwater is Critically Endangered, its distribution strongly overlaps with trawl fisheries, and it has limited capacity to adapt because it only lays one egg per year. It is speculated that trawl fisheries may also pose a threat to the Balearic shearwater (García-Barcelona et al., 2010; Laneri et al., 2010; Arcos, 2011), however the full effect is unknown. This finding could suggest a number of species that are vulnerable to bycatch in trawls might be unobserved and undocumented. This is likely because observer-based bycatch surveys do not fully quantify the total trawl-induced seabird mortality because birds that die after striking trawl cables commonly fall into the water (Eich et al., 2016).

An explanation for the differences between the species identified as vulnerable by the IUCN database and the vulnerability framework could be explained by limitations within the two approaches. On the one hand, our approach might be superior in some aspects. Firstly, the collation of IUCN threats, via expert opinion, is subjective and can contain bias (Hayward, 2009), therefore bycatch threats may be unreported. Secondly, there is very low observer coverage aboard fishing vessels, and existing data has poor species discrimination and weak quantification (Bartle, 1991; Weimerskirch, Capdeville & Duhamel, 2000; Sullivan, Reid & Bugoni, 2006; Anderson et al., 2011; Hedd et al., 2016; Suazo et al., 2017). Thus, bycatch mortality of high-risk species may be undetected by fishermen and observers, and therefore unreported to the IUCN. On the other hand, our framework may not fully capture fisheries interactions. Overlap is widely used as a proxy to assess interaction (Sonntag et al., 2012; Clay et al., 2019), yet species with similar amounts of overlap may demonstrate different rates of fisheries interaction events. It is presently unknown how overlap and interactions vary between all seabirds. Coupling extensive GPS tracking data (e.g., seabirdtracking.com) with Global Fishing Watch fishing effort data in future studies could further improve our vulnerability framework by better predicting how much seabirds interact with fishing boats (e.g. Torres, 2018). Further traits related to foraging behaviour or prey preference could be included within our sensitivity dimension to also improve our predictions. Finally, distributions of small-scale subsistence, and illegal, unreported and unregulated fishing activities were unavailable, and therefore not included in our vulnerability framework.

We recommend three core management actions for species with high scores in each vulnerability dimension. To reduce exposure to bycatch, it is necessary to manage the timing of fishing activities through time-area closures that prohibit fishing in an area or at specific times. To lower species sensitivity to bycatch, development of gear-specific mitigation methods that deter seabirds is imperative. Finally, to promote adaptive capacity, populations require support through reducing other threats (e.g., Dias et al., 2019), and promoting breeding success at colonies. These three management actions can, therefore, be strategically applied across the five vulnerability classes. The *high vulnerability* class encompasses species with high latent risk to bycatch. These species have the greatest priority for conservation intervention, and will require targeted research and implementation of all three core management actions described above. While the *potential adapters* class have high vulnerability, they may be able to adapt to bycatch because of their fast reproductive speeds. Therefore, *potential adapters* will require management for sensitivity and exposure, but may also benefit from monitoring adaptive responses at breeding colonies. Species within the *potential persisters* class have low sensitivity, but high vulnerability to bycatch. These species will require exposure and adaptive capacity management actions. The *potential future vulnerability* class contains species that could become vulnerable if their ranges overlap with fishing activity in the future because they have high adaptive capacity and sensitivity scores. The populations of these species should be routinely monitored to establish baselines for future comparison (e.g., Hebert et al., 2020), and potential threats should be recorded through space and time. Finally, species within the *low vulnerability* class should undergo routine monitoring. It is important to acknowledge that implementing such major management actions are challenging because they are often costly, take time, and require international collaboration.

Fishing activity and seabird distributions vary daily, seasonally and annually. We therefore acknowledge the limitation of using four years of fishing activity data and the broad distribution ranges of seabirds. However, our aim was to provide the first overall bycatch vulnerability estimate for all seabirds globally based on the best available data. The vulnerability framework employed here is highly adaptable to spatial and temporal variations in traits and threats (Foden et al., 2013; Potter, Crane & Hargrove, 2017). For example, the framework can be easily updated based on interannual and seasonal variation in fishing activity or changes in IUCN Red List category. We, therefore, highly recommend future studies couple extensive seabird tracking data with colony-specific trait information and regional fisheries patterns to provide a powerful and informative tool for local management.

In conclusion, we show that a trait-based approach can provide a unique perspective on the success of bycatch mitigation, capable of assessing the global seabird species pool. Furthermore, we overcome the conservation challenge of lack of bycatch data by identifying vulnerable non-target species through coupling readily available data on extrinsic threats with intrinsic traits in a flexible vulnerability framework. We recommend these trait-based approaches be applied at local scales with colony specific data and regional threat patterns to provide a powerful and informative tool for local management.

3.6 Co-authorship Statement

- I, **Cerren Richards**, designed and identified the research questions, analyzed the data, prepared the figures and tables, and authored the manuscript.
- **Robert S.C. Cooke** assisted with the conceptualization of the manuscript.
- **Diana Bowler** assisted with the conceptualization of the manuscript.
- **Kristina Boerder** contributed the Global Fishing Watch data.

- **Amanda E. Bates** assisted with the conceptualization of the manuscript, and assisted with coding the vulnerability framework in R.

Chapter 4 Conclusion

4.1 Integrated thesis summary

The abundance, availability and variability of seabird traits make these birds excellent candidates for trait-based studies (Fig. 4.1). The diverse ecological roles played by seabirds means that some species are affected by some pressures, while others are not. Therefore, traits act as ecological filters that can identify the most vulnerable species to anthropogenic threats. Through integrating a comprehensive dataset of seabird traits with species range maps and threat data, I tackle the overarching objective to uncover species' vulnerability patterns to anthropogenic pressures. The research in this thesis identified:

1. Globally and non-threatened seabirds occupy ecologically distinct areas in trait space (Chapter 2);
2. Species with similar traits and ecological strategies are being lost, whilst relatively unique species which tolerate human activities are of least concern (Chapter 2);
3. Traits can predict and quantify species vulnerabilities to threats (Chapters 2 & 3);
4. Traits can predict patterns of conservation outcomes (Chapter 3).

4.2 Conservation prioritizations

With high rates of extinction, population declines and changing biodiversity, there is pressure to identify the most effective conservation methods based on available funding (Murdoch et al., 2007; McCarthy et al., 2012). Over two chapters, I highlight priorities for the protection of ecological roles and species with high vulnerability to threats. Specifically, I categorise species into threat (Chapter 2 – habitat and direct threats) and vulnerability classes (Chapter 3) based on ecological strategies and a vulnerability framework. Species with high vulnerability and limited ecological strategies will benefit from targeted research and conservation strategies. For example, eliminating habitat threats through conserving important breeding and foraging habitats, and further mitigating bycatch and irradiating invasive species like rodents and cats at breeding colonies (Jones, 2010). However, these major solutions are challenging, often costly, take time, and require international collaboration. Species with low vulnerability and unique ecological strategies will require long-term monitoring of populations and the environment (e.g., Hebert et al., 2020). Furthermore, in Chapter 3, I identify regions that may benefit from the greatest ecological functioning protection through successful bycatch mitigation. Conservation strategies need to target areas undergoing rapid species and functional losses (e.g., between 30° – 70° in both hemispheres, and high loss of divers in the Northern hemisphere without bycatch intervention). Integrating these findings into future marine spatial planning frameworks (e.g. Augé et al., 2018) could provide new insights to support marine management and conservation.

4.3 Future directions of traits for seabird ecology and conservation

4.3.1 Gap filling

To achieve complete trait coverage for my list of 341 seabird species, I used a random-forest imputation procedure. While imputations increase analyses' sample size and statistical power, they can cause biased estimates and incorrect results (Schafer & Graham, 2002; Taugourdeau et al., 2014; Penone et al., 2014; Kim, Blomberg & Pandolfi, 2018). Therefore, it is important to compare outputs from with imputed and non-imputed data e.g., Cooke et al., 2019a; Cooke et al., 2019b). Performing the imputation and non-imputation approaches for all applicable analyses in Chapters 2 and 3, returned similar results for both and did not majorly alter my conclusions (Appendix A & B). To avoid the imputation approach in future seabird analyses, efforts should aim to fill the trait gaps for the 60 species. Gap filling will further provide the opportunities to test the results of this thesis. We were unable to include gill net fisheries and other fishing gear types into our analysis because there was insufficient coverage within the Global Fishing Watch dataset. However, as the coverage of satellites improves and the implementation of AIS expands across fleets, the vulnerability of seabirds to more fishing gears will be possible in the future.

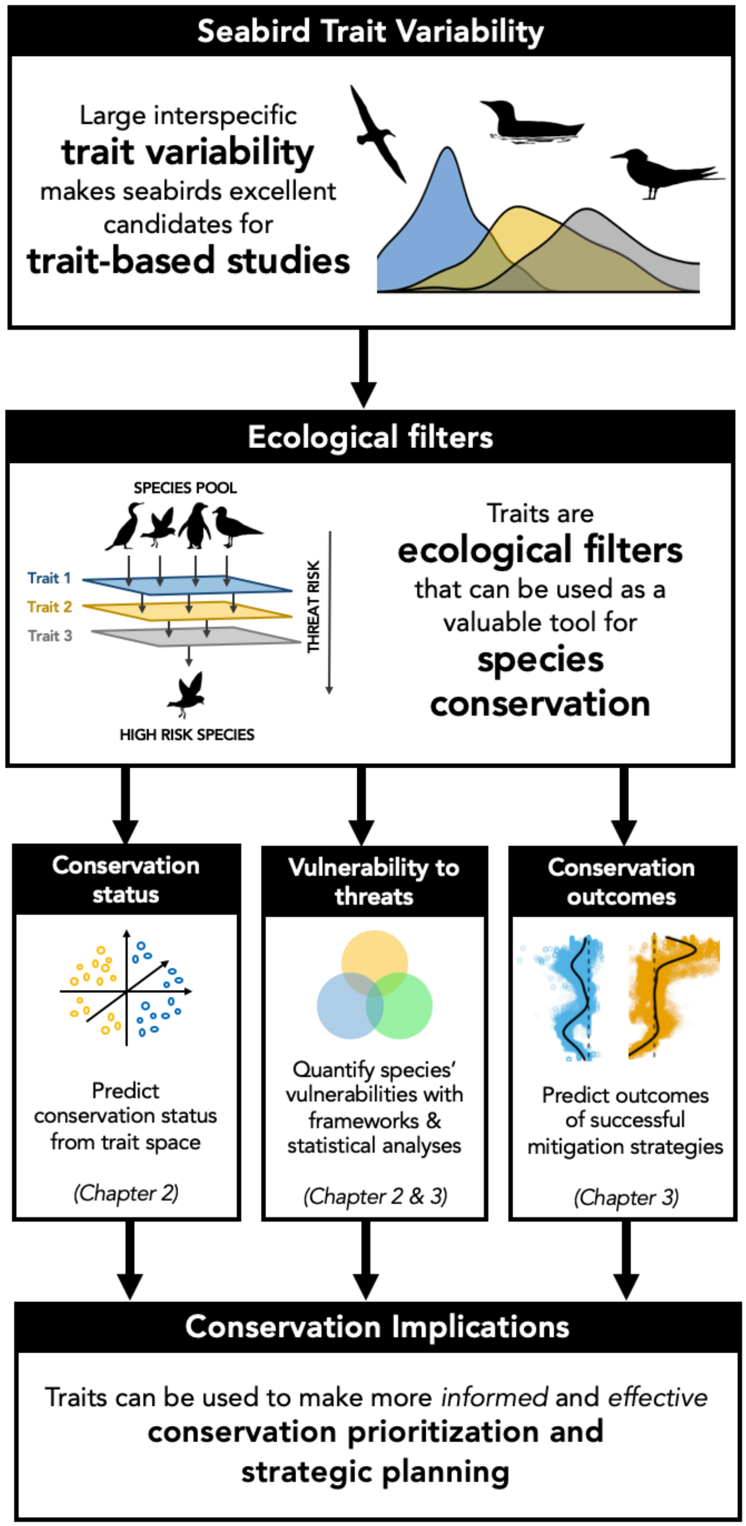


Figure 4.1 Conceptual diagram illustrating the potential value of traits for seabird conservation efforts.

4.3.2 Local scale

Throughout this thesis, I take a macroecological approach, however, I strongly recommend the reapplication of these traits for local conservation and management measures. In Chapter 3, I modified a trait-based vulnerability framework from Foden et al. (2013) and Potter, Crane & Hargrove (2017) to quantify seabird vulnerability to bycatch at a global scale. Because there is an abundance of seabird data from breeding colonies across the world, this vulnerability framework could be a valuable tool for local insights. For example, Newfoundland and Labrador is home to a globally significant number of breeding and wintering seabirds. Researchers have collected seabird morphological, behavioural, demographic and tracking data at colonies across the province for decades. Therefore, future studies could couple the extensive seabird tracking data with colony-specific trait information and regional fisheries patterns to capture region variations in seabird vulnerabilities.

4.3.3 Biodiversity and ecosystem functioning

Diversity and richness indices may provide valuable insights into how seabird biodiversity patterns relate to ecosystem functioning and how communities will restructure under future change (Tavares et al., 2019). Presently, there is a lack of understanding of these patterns at both local and global scales for seabirds (Pimiento et al., 2020). In Chapter 3, I began to tackle this knowledge gap with a community weighted mean approach. I found distinct spatial variation in seabird community traits across the globe, and shifts in community traits could be prevented with successful bycatch mitigation strategies. Furthermore, in a preliminary analysis, I calculated global patterns of seabird functional diversity (Rao's Q) and species richness by combining eight traits with BirdLife International distributions polygons. Functional diversity indicates the difference between species' traits, while species richness is the number of different species in a community. These preliminary insights revealed distinct variations in seabird biodiversity (Fig. 4.2). For example, functional diversity is greatest in the mid-Atlantic and Indian Oceans, whereas species richness is greatest in the south Pacific and Southern Oceans. These differences suggest traits will be a valuable tool for future research.

Questions of interest may include: (1) how do ecosystem functions vary through space and time based on seabird movements (breeding to wintering), and (2) how are marine and terrestrial protected areas conserving hotspots of seabird biodiversity.

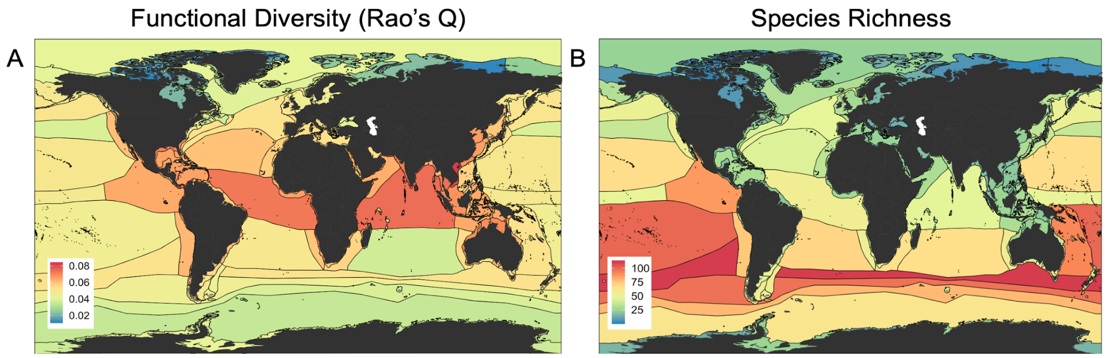


Figure 4.2 Examples of potential indices that could be used to quantify and visualise patterns in seabird diversity (A) and richness (B).

4.4 Conclusion

In conclusion, compiling a dataset of traits for all seabirds, for the first time, offered exciting insights into the ecological strategies of seabirds. Furthermore, these traits also opened opportunities to evaluate seabird vulnerabilities when data are scarce, and allowed the quantification of potential conservation gains. I hope, through the work presented in this thesis, seabird traits can further be used to understand patterns of seabird biodiversity at local and global scales, and incorporated into management strategies to advance the conservation of highly threatened seabirds.

References

Alverson DL, Freeberg MH, Pope JG, Murawski SA. 1994. *A global assessment of fisheries bycatch and discards*. Rome.

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. DOI: 10.3354/esr00347.

Arcos JM. 2011. International species action plan for the Balearic shearwater, Puffinus mauretanicus. *SEO/BirdLife & BirdLife International.*

Augé AA, Dias MP, Lascelles B, Baylis AMM, Black A, Boersma PD, Catry P, Crofts S, Galimberti F, Granadeiro JP, Hedd A, Ludynia K, Masello JF, Montevecchi W, Phillips RA, Pütz K, Quillfeldt P, Rebstock GA, Sanvito S, Staniland IJ, Stanworth A, Thompson D, Tierney M, Trathan PN, Croxall JP. 2018. Framework for mapping key areas for marine megafauna to inform Marine Spatial Planning: The Falkland Islands case study. *Marine Policy* 92:61–72. DOI: 10.1016/j.marpol.2018.02.017.

Barnosky AD, Matzke N, Tomiya S, Wogan GOU, Swartz B, Quental TB, Marshall C, McGuire JL, Lindsey EL, Maguire KC, Mersey B, Ferrer EA. 2011. Has the Earth's sixth mass extinction already arrived? *Nature* 471:51–57. DOI: 10.1038/nature09678.

Bartle A. 1991. Incidental capture of seabirds in the New Zealand and sub-Antarctic squid trawl fishery, 1990. *Bird Conservation International* 1:351–359.

Beauchard O, Veríssimo H, Queirós AM, Herman PMJ. 2017. The use of multiple biological traits in marine community ecology and its potential in ecological indicator development. *Ecological Indicators* 76:81–96. DOI: 10.1016/j.ecolind.2017.01.011.

Belmaker J, Jetz W. 2015. Relative roles of ecological and energetic constraints , diversification rates and region history on global species richness gradients. *Ecology Letters* 18:563–571. DOI: 10.1111/ele.12438.

Belmaker J, Parravicini V, Kulbicki M. 2014. Ecological traits and environmental affinity explain Red Sea fish introduction into the Mediterranean. *Global Change Biology* 20:680–680. DOI: 10.1111/gcb.12132.

Ben-Shachar MS, Makowski D, Lüdecke D. 2020. Compute and interpret indices of effect size.

Bird JP, Martin R, Akçakaya HR, Gilroy J, Burfield IJ, Garnett ST, Symes A, Taylor J, Şekercioğlu ÇH, Butchart SHM. 2020. Generation lengths of the world's birds and their implications for extinction risk. *Conservation Biology*. DOI:

10.1111/cobi.13486.

Bivand R, Lewin-Koh N. 2018. maptools: Tools for Handling Spatial Objects.

Blomberg SP, Garland T, Ives AR. 2003. Testing for phylogenetic signal in comparative data: behavioral traits are more liable. *Evolution* 57:717–745. DOI: 10.1111/j.0014-3820.2003.tb00285.x.

Bost CA, le Maho Y. 1993. Seabirds as bio-indicators of changing marine ecosystems: new perspectives. *Acta Oecologia* 14:463–470.

Bowler DE, Bjorkman AD, Dornelas M, Myers-Smith IH, Navarro LM, Niamir A, Supp SR, Waldock C, Winter M, Vellend M, Blowes SA, Böhning-Gaese K, Bruelheide H, Elahi R, Antão LH, Hines J, Isbell F, Jones HP, Magurran AE, Cabral JS, Bates AE. 2020. Mapping human pressures on biodiversity across the planet uncovers anthropogenic threat complexes. *People and Nature* 00:1–15. DOI: 10.1002/pan3.10071.

Brum FT, Graham CH, Costa GC, Hedges SB, Penone C, Radeloff VC, Rondinini C, Loyola R, Davidson AD. 2017. Global priorities for conservation across multiple dimensions of mammalian diversity. *Proceedings of the National Academy of Sciences* 114:7641–7646. DOI: 10.1073/pnas.1706461114.

Buisson L, Grenouillet G, Villéger S, Canal J, Laffaille P. 2013. Toward a loss of functional diversity in stream fish assemblages under climate change. *Global Change Biology* 19:387–400. DOI: 10.1111/gcb.12056.

Butt N, Gallagher R. 2018. Using species traits to guide conservation actions under climate change. *Climatic Change* 151:317–332. DOI: 10.1007/s10584-018-2294-z.

van Buuren S, Groothuis-Oudshoorn K. 2011. mice: Multivariate imputation by chained equations in R. *Journal of Statistical Software* 45:1–67. DOI: 10.18637/jss.v045.i03.

Cardillo M, Mace GM, Jones KE, Bielby J, Bininda-Emonds ORP, Sechrest W, Orme CDL, Purvis A. 2005. Multiple Causes of High Extinction Risk in Large Mammal Species. *Science* 309:1239–1241. DOI: 10.1126/science.1116030.

Cardinale BJ, Duffy JE, Gonzalez A, Hooper DU, Perrings C, Venail P, Narwani A, Mace GM, Tilman D, Wardle DA, Kinzig AP, Daily GC, Loreau M, Grace JB, Larigauderie A, Srivastava DS, Naeem S. 2012. Biodiversity loss and its impact on humanity. *Nature* 486:59–67. DOI: 10.1038/nature11148.

Chamberlain S. 2018. rredlist: “IUCN” Red List Client.

Chapin FS, Zavaleta ES, Eviner VT, Naylor RL, Vitouset PM, Reynolds HL, Hooper DU, Lavorel S, Sala OE, Hobbie SE, Mack MC, Díaz S. 2000. Three-Dimensional

Imaging of the Face: A Comparison between Three Different Imaging Modalities. *Nature* 405:234–242. DOI: 10.1093/asj/sjx227.

Chavent M, Kuentz-Simonet V, Labenne A, Saracco J. 2014. Multivariate Analysis of Mixed Data: The R Package PCAmixdata. :1–31.

Chavent M, Kuentz V, Labenne A, Liquet B, Saracco J. 2017. PCAmixdata: Multivariate Analysis of Mixed Data.

Clarke K., Warwick R. 2001. *Change in marine communities: an approach to statistical analysis and interpretation, 2nd edition*. Plymouth: PRIMER-E.

Clay TA, Small C, Tuck GN, Pardo D, Carneiro APB, Wood AG, Croxall JP, Crossin GT, Phillips RA. 2019. A comprehensive large - scale assessment of fisheries bycatch risk to threatened seabird populations. *Journal of Applied Ecology* 56:1882–1893. DOI: 10.1111/1365-2664.13407.

Cooke RSC, Bates AE, Eigenbrod F. 2019. Global trade-offs of functional redundancy and functional dispersion for birds and mammals. *Global Ecology and Biogeography* 28:484–495. DOI: 10.1111/geb.12869.

Cooke RSC, Eigenbrod F, Bates AE. 2019. Projected losses of global mammal and bird ecological strategies. *Nature Communications* 10:2279. DOI: 10.1038/s41467-019-10284-z.

Croxall JP. 2008. The role of science and advocacy in the conservation of Southern Ocean albatrosses at sea. *Bird Conservation International* 18:13–29. DOI: 10.1017/S0959270908000300.

Croxall JP, Butchart SHM, Lescelles B, Stattersfield AJ, Sullivan B, Symes A, Taylor P. 2012. Seabird conservation status, threats and priority actions: a global assessement. *Bird Conservation International* 22:1–34. DOI: 10.1017/S095.

D'Aloia CC, Naujokaitis-Lewis I, Blackford C, Chu C, Curtis JMR, Darling E, Guichard F, Leroux SJ, Martensen AC, Rayfield B, Sunday JM, Xuereb A, Fortin M-J. 2019. Coupled Networks of Permanent Protected Areas and Dynamic Conservation Areas for Biodiversity Conservation Under Climate Change. *Frontiers in Ecology and Evolution* 7:27. DOI: 10.3389/fevo.2019.00027.

Davidson AD, Hamilton MJ, Boyer AG, Brown JH, Ceballos G. 2009. Multiple ecological pathways to extinction in mammals. *Proceedings of the National Academy of Sciences of the United States of America* 106:10702–10705. DOI: 10.1073/pnas.0901956106.

Dias MP, Martin R, Pearmain EJ, Burfield IJ, Small C, Phillips RA, Yates O, Lascelles B, Borboroglu PG, Croxall JP. 2019. Threats to seabirds: A global assessment.

Biological Conservation 237:525–537. DOI: 10.1016/j.biocon.2019.06.033.

Diniz-Filho JAF, Bini LM, Rangel TF, Morales-Castilla I, Olalla-Tárraga MÁ, Rodríguez MÁ, Hawkins BA. 2012a. On the selection of phylogenetic eigenvectors for ecological analyses. *Ecography* 35:239–249. DOI: 10.1111/j.1600-0587.2011.06949.x.

Diniz-Filho JAF, Rangel TF, Santos T, Bini LM. 2012b. Exploring patterns of interspecific variation in quantitative traits using sequential phylogenetic eigenvector regression. *Evolution* 66:1079–1090. DOI: 10.1111/j.1558-5646.2011.01499.x.

Dornelas M, Gotelli NJ, McGill B, Shimadzu H, Moyes F, Sievers C, Magurran AE. 2014. Assemblage Time Series Reveal Biodiversity Change but Not Systematic Loss. *Science* 344:296–299. DOI: 10.1126/science.1248484.

Doughty CE, Roman J, Faurby S, Wolf A, Haque A, Bakker ES, Malhi Y, Dunning JB, Svenning J-C. 2016. Global nutrient transport in a world of giants. *Proceedings of the National Academy of Sciences* 113:868–873. DOI: 10.1073/pnas.1502549112.

Duarte L, Debastiani V, Carlucci M, Diniz-Filho J. 2017. Analyzing community-weighted trait means across environmental gradients: should phylogeny stay or should it go? *Ecology* 99:385–398. DOI: 10.1111/ijlh.12426.

Duffy E. 2003. Biodiversity loss, trophic skew and ecosystem functioning. *Ecology Letters* 6:680–687.

Eich AM, Mabry KR, Wright SK, Fitzgerald SM. 2016. Seabird bycatch and mitigation efforts in Alaska Fisheries : summary report, 2007 through 2015. DOI: http://doi.org/10.7289/V5/TM-F/AKR-12.

Fayet AL, Freeman R, Anker-Nilssen T, Diamond A, Erikstad KE, Fifield D, Fitzsimmons MG, Hansen ES, Harris MP, Jessopp M, Kouwenberg AL, Kress S, Mowat S, Perrins CM, Petersen A, Petersen IK, Reiertsen TK, Robertson GJ, Shannon P, Sigurðsson IA, Shoji A, Wanless S, Guilford T. 2017. Ocean-wide Drivers of Migration Strategies and Their Influence on Population Breeding Performance in a Declining Seabird. *Current Biology* 27:3871-3878.e3. DOI: 10.1016/j.cub.2017.11.009.

Foden W, Butchart SHM, Stuart S, Vie´ J-C, Resit HA, Angulo A, DeVantier LM, Gutsche A, Turak E, Cao L, Donner SD, Katariya V, Bernard R, Holland RA, Hughes AF, O'Hanlon SE, Garnett ST, Sekercioglu CH, Mace GM. 2013. Identifying the World 's Most Climate Change Vulnerable Species : A Systematic Trait-Based Assessment of all Birds , Amphibians and Corals. *PLOS ONE* 8:e65427. DOI: 10.1371/journal.pone.0065427.

Gallagher R V, Falster DS, Maitner BS, Salguero-gómez R, Vandvik V, Pearse WD, Schneider FD, Kattge J, Poelen JH, Madin JS, Ankenbrand MJ, Penone C, Feng X, Adams VM, Alroy J, Andrew SC, Balk MA, Bland LM, Boyle BL, Bravo-avila CH, Brennan I, Carthey AJR, Catullo R, Cavazos BR, Conde DA, Ray CA, Rossetto M, Sauquet H, Sparrow B, Spasojevic MJ, Telford RJ, Tobias JA, Violle C, Walls R, Weiss KCB, Westoby M, Wright IJ, Enquist BJ. 2020. Open Science principles for accelerating trait-based science across the Tree of Life. *Nature Ecology & Evolution* 4:294–303. DOI: 10.1038/s41559-020-1109-6.

García-Barcelona S, Macías D, Urbina J, Estrada A, Real R, Báez J. 2010. Modelling abundance and distribution of seabird by-catch in the Spanish Mediterranean longline fishery. *Ardeola: revista ibérica de ornitología* 57:65–78.

Geldmann J, Joppa LN, Burgess ND. 2014. Mapping Change in Human Pressure Globally on Land and within Protected Areas. *Conservation Biology* 28:1604–1616. DOI: 10.1111/cobi.12332.

Gonzalez-Suarez M, Gomez A, Revilla E. 2013. Which intrinsic traits predict vulnerability to extinction depends on the actual threatening processes. *Ecosphere* 4:1–16. DOI: 10.1890/ES12-00380.1.

González-Suárez M, Zanchetta Ferreira F, Grilo C. 2018. Spatial and species-level predictions of road mortality risk using trait data. *Global Ecology and Biogeography* 27:1093–1105. DOI: 10.1111/geb.12769.

Graham NAJ, Wilson SK, Carr P, Hoey AS, Jennings S, MacNeil MA. 2018a. Seabirds enhance coral reef productivity and functioning in the absence of invasive rats. *Nature* 559:250–253. DOI: 10.1038/s41586-018-0202-3.

Graham NAJ, Wilson SK, Carr P, Hoey AS, Jennings S, MacNeil MA. 2018b. Seabirds enhance coral reef productivity and functioning in the absence of invasive rats. *Nature* 559:250–253. DOI: 10.1038/s41586-018-0202-3.

Gross K, Cardinale BJ. 2005. The functional consequences of random vs. ordered species extinctions. *Ecology Letters* 8:409–418. DOI: 10.1111/j.1461-0248.2005.00733.x.

Guenard G, Legendre P. 2018. MPSEM: Modeling Phylogenetic Signals using Eigenvector Maps.

Guiet J, Galbraith E, Kroodsma D, Worm B. 2019. Seasonal variability in global industrial fishing effort. *PLoS ONE* 14:1–17. DOI: 10.1371/journal.pone.0216819.

Gustafsson C, Norkko A. 2019. Quantifying the importance of functional traits for primary production in aquatic plant communities. *Journal of Ecology*:154–166. DOI: 10.1111/1365-2745.13011.

Halpern BS, Walbridge S, Selkoe KA, Kappel C V, Micheli F, D'Agrosa C, Bruno JF, Casey KS, Ebert C, Fox HE, Fujita R, Heinemann D, Lenihan HS, Madin EMP, Perry MT, Selig ER, Spalding M, Steneck R, Watson R. 2008. A Global Map of Human Impact on Marine Ecosystems. *Science* 319:948–952. DOI: 10.1126/science.1149345.

Hayward MW. 2009. The need to rationalize and prioritize threatening processes used to determine threat status in the IUCN red list. *Conservation Biology* 23:1568–1576. DOI: 10.1111/j.1523-1739.2009.01260.x.

Hebert CE, Weseloh DVC, Arts MT, de Solla SR, Moore DJ, Paterson G, Pekarik C. 2020. Trends in herring gull egg quality over four decades reflect ecosystem state. *Journal of Great Lakes Research* 46:538–548. DOI: 10.1016/J.JGLR.2020.03.004.

Hedd A, Regular PM, Wilhelm SI, Rail J-F, Drolet B, Fowler M, Pekarik C, Robertson GJ. 2016. Characterization of seabird bycatch in eastern Canadian waters, 1998–2011, assessed from onboard fisheries observer data. *Aquatic Conservation: Marine and Freshwater Ecosystems* 26:530–548. DOI: 10.1002/aqc.2551.

Hijmans RJ. 2019. raster: Geographic Data Analysis and Modeling.

IPBES. 2019. *Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. Bonn, Germany.

IUCN. 2020.The IUCN Red List of Threatened Species. Version 2020-1. *Available at https://www.iucnredlist.org*

Jones HP. 2010. Seabird islands take mere decades to recover following rat eradication. *Ecological Applications* 20:2075–2080. DOI: 10.1890/07-1650.1.

Kim SW, Blomberg SP, Pandolfi JM. 2018. Transcending data gaps: a framework to reduce inferential errors in ecological analyses. *Ecology Letters* 21:1200–1210. DOI: 10.1111/ele.13089.

Komoroske LM, Lewison RL. 2015. Addressing fisheries bycatch in a changing world. *Frontiers in Marine Science* 2:83. DOI: 10.3389/fmars.2015.00083.

Kroodsma DA, Mayorga J, Hochberg T, Miller NA, Boerder K, Ferretti F, Wilson A, Bergman B, White TD, Block BA, Woods P, Sullivan B, Costello C, Worm B. 2018. Tracking the global footprint of fisheries. *Science* 359:904–908. DOI: 10.1126/science.aao5646.

Laliberté E, Legendre P. 2010a. *A distance-based framework for measuring functional diversity from multiple traits*.

Laliberté E, Legendre P. 2010b. A distance-based framework for measuring functional diversity from multiple traits. *Ecology* 91:299–305.

Laliberté E, Legendre P, Shipley B. 2014. FD: measuring functional diversity from multiple traits, and other tools for functional ecology.

Lamanna C, Blonder B, Violle C, Kraft NJB, Sandel B, Šímová I, Donoghue JC, Svenning J-C, McGill BJ, Boyle B, Buzzard V, Dolins S, Jørgensen PM, Marcuse-Kubitza A, Morueta-Holme N, Peet RK, Piel WH, Regetz J, Schildhauer M, Spencer N, Thiers B, Wiser SK, Enquist BJ. 2014. Functional trait space and the latitudinal diversity gradient. *Proceedings of the National Academy of Sciences* 111:13745 LP – 13750. DOI: 10.1073/pnas.1317722111.

Laneri K, Louzao M, Martínez-Abraín A, Arcos J, Belda E, Guallart J, M G, R M, Oro D. 2010. Trawling regime influences longline seabird bycatch in the Mediterranean: New insights from a small-scale fishery. *Marine Ecology Progress Series* 420:241–252. DOI: 10.3354/meps08847.

Lepš J, de Bello F, Lavorel S, Berman S. 2006. Quantifying and interpreting functional diversity of natural communities: Practical considerations matter. *Preslia* 78:481–501.

Lewison RL, Crowder LB, Read AJ, Freeman SA. 2004. Understanding impacts of fisheries bycatch on marine megafauna. *Trends in Ecology and Evolution* 19:598–604. DOI: 10.1016/j.tree.2004.09.004.

Mace GM, Norris K, Fitter AH. 2012. Biodiversity and ecosystem services : a multilayered relationship. *Trends in Ecology and Evolution* 27:19–26. DOI: 10.1016/j.tree.2011.08.006.

Mace G, Possingham H, Leader-Williams N. 2007. *Prioritizing choices in conservation. In: Macdonald D, Service K (eds) Key topics in conservation biology.* Oxford: Blackwell Publishing.

Magurran AE. 2004. *Measuring Biological Diversity*. Oxford, United Kingdom: Blackwell.

Maree BA, Wanless RM, Fairweather TP, Sullivan BJ, Yates O. 2014. Significant reductions in mortality of threatened seabirds in a South African trawl fishery. *Animal Conservation* 17:520–529. DOI: 10.1111/acv.12126.

McCarthy DP, Donald PF, Scharlemann JPW, Buchanan GM, Balmford A, Green JMH, Bennun LA, Burgess ND, Fishpool LDC, Garnett ST, Leonard DL, Maloney RF, Morling P, Schaefer HM, Symes A, Wiedenfeld DA, Butchart SHM. 2012. Financial Costs of Meeting Global Biodiversity Conservation Targets: Current Spending and Unmet Needs. *Science* 338:946–949. DOI: 10.1126/science.1229803.

McGill BJ, Enquist BJ, Weiher E, Westoby M. 2006. Rebuilding community ecology from functional traits. *Trends in Ecology & Evolution* 21:178–185. DOI: 10.1016/j.tree.2006.02.002.

Mori AS, Furukawa T, Sasaki T. 2013. Response diversity determines the resilience of ecosystems to environmental change. *Biological Reviews* 88:349–364. DOI: 10.1111/brv.12004.

Murdoch W, Polasky S, Wilson KA, Possingham HP, Kareiva P, Shaw R. 2007. Maximizing return on investment in conservation. *Biological Conservation* 139:375–388. DOI: https://doi.org/10.1016/j.biocon.2007.07.011.

Murray KA, Rosauer D, McCallum H, Skerratt LF. 2011. Integrating species traits with extrinsic threats: Closing the gap between predicting and preventing species declines. *Proceedings of the Royal Society B: Biological Sciences* 278:1515–1523. DOI: 10.1098/rspb.2010.1872.

Oksanen J, Blanchet FG, Friendly M, Kindt R, Legendre P, McGlinn D, Minchin PR, O'Hara RB, Simpson GL, Solymos P, Stevens MHH, Szoecs E, Wagner H. 2018. vegan: Community Ecology Package.

Pagel M. 1999. Inferring the historical patterns of biological evolution. *Nature* 401:877–884. DOI: 10.1038/44766.

Paleczny M, Hammill E, Karpouzi V, Pauly D. 2015. Population Trend of the World's Monitored Seabirds, 1950-2010. *PLOS ONE* 10:e0129342. DOI: 10.1371/journal.pone.0129342.

De Palma A, Kuhlmann M, Roberts SPM, Potts SG, Börger L, Hudson LN, Lysenko I, Newbold T, Purvis A. 2015. Ecological traits affect the sensitivity of bees to land-use pressures in European agricultural landscapes. *Journal of Applied Ecology* 52:1567–1577. DOI: 10.1111/1365-2664.12524.

Paradis E, Claude J, Strimmer K. 2004. APE: Analyses of Phylogenetics and Evolution in R language. *Bioinformatics* 20:289–290. DOI: 10.1093/bioinformatics/btg412.

Pardo D, Forcada J, Wood AG, Tuck GN, Ireland L, Pradel R, Croxall JP, Phillips RA. 2017. Additive effects of climate and fisheries drive ongoing declines in multiple albatross species. *Proceedings of the National Academy of Sciences* 114:E10829–E10837. DOI: 10.1073/pnas.1618819114.

Parsons M, Mitchell I, Butler A, Ratcliffe N, Frederiksen M, Foster S, Reid JB. 2008. Seabirds as indicators of the marine environment. *ICES Journal of Marine Science* 65:1520–1526. DOI: 10.1093/icesjms/fsn155.

Peñaranda DA, Simonetti JA. 2015. Predicting and setting conservation priorities for

Bolivian mammals based on biological correlates of the risk of decline. *Conservation Biology* 29:834–843. DOI: 10.1111/cobi.12453.

Penone C, Davidson AD, Shoemaker KT, Di Marco M, Rondinini C, Brooks TM, Young BE, Graham CH, Costa GC. 2014. Imputation of missing data in life-history trait datasets: which approach performs the best? *Methods in Ecology and Evolution* 5:961–970. DOI: 10.1111/2041-210X.12232.

Pimiento C, Leprieur F, Silvestro D, Lefcheck JS, Albouy C, Rasher DB, Davis M, Svenning J-C, Griffin JN. 2020. Functional diversity of marine megafauna in the Anthropocene. *Science Advances* 6:eaay7650.

Pollock LJ, Thuiller W, Jetz W. 2017. Large conservation gains possible for global biodiversity facets. *Nature* 546:141–144. DOI: 10.1038/nature22368.

Potter KM, Crane BS, Hargrove WW. 2017. A United States national prioritization framework for tree species vulnerability to climate change. *New Forests* 48:275–300. DOI: 10.1007/s11056-017-9569-5.

Prum RO, Berv JS, Dornburg A, Field DJ, Townsend JP, Lemmon EM, Lemmon AR. 2015. A comprehensive phylogeny of birds (Aves) using targeted next-generation DNA sequencing. *Nature* 526:569–573. DOI: 10.1038/nature15697.

Rao M, Larsen T. 2010. Ecological Consequences of Extinction. *Lessons in Conservation* 3:25–53. DOI: 10.1126/science.1235225.

Richards C, Padget O, Guilford T, Bates AE. 2019. Manx shearwater (*Puffinus puffinus*) rafting behaviour revealed by GPS tracking and behavioural observations. *PeerJ* 7:e7863. DOI: 10.7717/peerj.7863.

Ripple WJ, Wolf C, Newsome TM, Hoffmann M, Wirsing AJ, McCauley DJ. 2017. Extinction risk is most acute for the world's largest and smallest vertebrates. *Proceedings of the National Academy of Sciences* 114:10678–10683. DOI: 10.1073/pnas.1702078114.

Rodríguez A, Arcos JM, Bretagnolle V, Dias MP, Holmes ND, Louzao M, Provencher J, Raine AF, Ramírez F, Rodríguez B, Ronconi RA, Taylor RS, Bonnaud E, Borrelle SB, Cortés V, Descamps S, Friesen VL, Genovart M, Hedd A, Hodum P, Humphries GRW, Le Corre M, Lebarbenchon C, Martin R, Melvin EF, Montevecchi WA, Pinet P, Pollet IL, Ramos R, Russell JC, Ryan PG, Sanz-Aguilar A, Spatz DR, Travers M, Votier SC, Wanless RM, Woehler E, Chiaradia A. 2019. Future directions in conservation research on petrels and shearwaters. *Frontiers in Marine Science* 6:94. DOI: 10.3389/fmars.2019.00094.

Ronconi RA, Lascelles BG, Langham GM, Reid JB, Oro D. 2012. The role of seabirds in Marine Protected Area identification, delineation, and monitoring: Introduction and synthesis. *Biological Conservation* 156:1–4. DOI: https://doi.org/10.1016/j.biocon.2012.02.016.

Rousseau Y, Watson RA, Blanchard JL, Fulton EA. 2019. Evolution of global marine fishing fleets and the response of fished resources. *Proceedings of the National Academy of Sciences* 116:12238–12243. DOI: 10.1073/pnas.1820344116.

Sala E, Mayorga J, Costello C, Kroodsma D, Palomares MLD, Pauly D, Sumaila UR, Zeller D. 2018. The economics of fishing the high seas. *Science Advances* 4:eaat2504. DOI: 10.1126/sciadv.aat2504.

Schafer JL, Graham JW. 2002. Missing data: our view of the state of the art. *Psychological methods* 7:147—177. DOI: 10.1037/1082-989x.7.2.147.

Schmitz O, Wilmers C, Leroux S, Doughty C, Atwood T, Galetti M, Davies A, Goetz S. 2018. Animals and the zoogeochemistry of the carbon cycle. *Science* 362:eaar3213. DOI: 10.1126/science.aar3213.

Seco Pon JP, García G, Copello S, Moretinni A, Lértora HP, Pedrana J, Mauco L, Favero M. 2012. Seabird and marine mammal attendance in the Chub mackerel Scomber japonicas semi-industrial Argentinian purse seine fishery. *Ocean & Coastal Management* 64:56–66.

Senko J, White ER, Heppell SS, Gerber LR. 2014. Comparing bycatch mitigation strategies for vulnerable marine megafauna. *Animal Conservation* 17:5–18. DOI: 10.1111/acv.12051.

Sonntag N, Schwemmer H, Fock HO, Bellebaum J, 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.

Speakman JR. 2005. Body size, energy metabolism and lifespan. *Journal of Experimental Biology* 208:1717–1730. DOI: 10.1242/jeb.01556.

Stekhoven DJ, Bühlmann P. 2012. MissForest — non-parametric missing value imputation for mixed-type data. *Bioinformatics* 28:112–118. DOI: 10.1093/bioinformatics/btr597.

Stuart-Smith RD, Bates AE, Lefcheck JS, Duffy JE, Baker SC, Thomson RJ, Stuart-Smith JF, Hill NA, Kininmonth SJ, Airoldi L, Becerro MA, Campbell SJ, Dawson TP, Navarrete SA, Soler GA, Strain EMA, Willis TJ, Edgar GJ. 2013. Integrating abundance and functional traits reveals new global hotspots of fish diversity. *Nature* 501:539–542.

Sturges HA. 1926. The choice of a class interval. *Journal of the American Statistical Association* 21:65–66.

Suazo CG, Oliveira N, Debski I, Mangel JC, Alfaro-Shigueto J, Azocar J, García-Alberto G, Velarde E. 2017. Seabird bycatch in purse seine fisheries: Status of knowledge and mitigation measures. *ACAP - Eighth Meeting of the Seabird Bycatch Working Group*.

Sullivan B, Reid T, Bugoni L. 2006. Seabird mortality on factory trawlers in the Falkland Islands and beyond. *Biological Conservation* 131:495–504.

Swenson NG. 2014. Phylogenetic imputation of plant functional trait databases. *Ecography* 37:105–110. DOI: 10.1111/j.1600-0587.2013.00528.x.

Taugourdeau S, Villerd J, Plantureux S, Huguenin-Elie O, Amiaud B. 2014. Filling the gap in functional trait databases: use of ecological hypotheses to replace missing data. *Ecology and evolution* 4:944–58. DOI: 10.1002/ece3.989.

Tavares DC, Moura JF, Acevedo-Trejos E, Merico A. 2019. Traits Shared by Marine Megafauna and Their Relationships With Ecosystem Functions and Services. *Frontiers in Marine Science* 6:262. DOI: 10.3389/fmars.2019.00262.

Team RC. 2018. R: A language and environment for statistical computing.

Tilman D, Isbell F, Cowles JM. 2014. Biodiversity and ecosystem functioning. *Annual Review of Ecology, Evolution, and Systematics* 45:471–493. DOI: 10.1146/annurev-ecolsys-120213-091917.

Torres L. 2018.Moving from overlap to interaction in seabird-fishery analysis. *Available at http://blogs.oregonstate.edu/gemmlab/2018/12/10/moving-from-overlap-to-interaction-in-seabird-fishery-analysis/* (accessed September 8, 2020).

Veitch CR, Clout MN, Martin A., Russell J., West CJ, (eds.). 2019. *Island invasives: scaling up to meet the challenge*. Gland, Switzerland: IUCN.

Velarde E, Anderson DW, Ezcurra E. 2019. Seabird clues to ecosystem health. *Science* 365:116–117.

Venter O, Sanderson EW, Magrach A, Allan JR, Beher J, Jones KR, Possingham HP, Laurance WF, Wood P, Fekete M, Levy MA, Watson JEM. 2016. Sixteen years of change in the global terrestrial human footprint and implications for biodiversity conservation. *Nature Communications* 7:12558. DOI: 10.1038/ncomms12558.

Vié J-C, Hilton-Taylor C, Stuart SN. 2009. *Wildlife in a Changing World – An Analysis of the 2008 IUCN Red List of Threatened Species*. Gland, Switzerland.

Vilela B, Villalobos F. 2015. letsR : a new R package for data handling and analysis in macroecology. *Methods in Ecology and Evolution* 6:1229–1234. DOI: 10.1111/2041-210X.12401.

Villéger S, Mason N, Mouillot D. 2008. New multidimensional functional diversity indices for a multifaceted framework in functional ecology. *Ecology* 89:2290–2301.

Violle C, Navas M-L, Vile D, Kazakou E, Fortunel C, Hummel I, Garnier E. 2007. Let the concept of trait be functional! *Oikos* 116:882–892. DOI: 10.1111/j.2007.0030-1299.15559.x.

Votier SC, Bearhop S, Witt MJ, Inger R, Thompson D, Newton J. 2010. Individual responses of seabirds to commercial fisheries revealed using GPS tracking, stable isotopes and vessel monitoring systems. *Journal of Applied Ecology* 47:487–497. DOI: 10.1111/j.1365-2664.2010.01790.x.

Wakefield ED, Phillips RA, Matthiopoulos J. 2009. Quantifying habitat use and preferences of pelagic seabirds using individual movement data: A review. *Marine Ecology Progress Series* 391:165–182. DOI: 10.3354/meps08203.

Wardle DA, Bellingham PJ, Bonner KI, Mulder CPH. 2009. Indirect effects of invasive predators on litter decomposition and nutrient resorption on seabird-dominated islands. *Ecology* 90:452–464. DOI: 10.1890/08-0097.1.

Wardle DA, Bellingham PJ, Fukami T, Bonner KI. 2012. Soil-mediated indirect impacts of an invasive predator on plant growth. *Biology Letters* 8:574–577. DOI: 10.1098/rsbl.2012.0201.

Weimerskirch H, Capdeville D, Duhamel G. 2000. Factors affecting the number and mortality of seabirds attending trawlers and long-liners in the Kerguelen area. *Polar Biology* 23:236–249.

Wilman H, Belmaker J, Simpson J, de la Rosa C, Rivadeneira MM, Jetz W. 2014. EltonTraits 1.0: Species-level foraging attributes of the world's birds and mammals. *Ecology* 95:2027. DOI: 10.1890/13-1917.1.

Wing S, Jack L, Shatova O, Leichter J, Barr D, Frew R, Gault-Ringold M. 2014. Seabirds and marine mammals redistribute bioavailable iron in the Southern Ocean. *Marine Ecology Progress Series* 510:1–13.

Woolmer G, Trombulak SC, Ray JC, Doran PJ, Anderson MG, Baldwin RF, Morgan A, Sanderson EW. 2008. Rescaling the Human Footprint : A tool for conservation planning at an ecoregional scale. *Landscape and Urban Planning* 87:42–53. DOI: 10.1016/j.landurbplan.2008.04.005.

World BI and H of the B of the. 2017.Bird species distribution maps of the world. Version 2017.2. *Available at http://datazone.birdlife.org/species/requestdis*

Worm B, Paine RT. 2016. Humans as a Hyperkeystone Species. *Trends in Ecology and Evolution* 31:600–607. DOI: 10.1016/j.tree.2016.05.008.

Yachi S, Loreau M. 1999. Biodiversity and ecosystem productivity in a fluctuating environment: the insurance hypothesis. *Proceedings of the National Academy of Sciences* 96:1463–1468.

Zhou C, Jiao Y, Browder J. 2019. Seabird bycatch vulnerability to pelagic longline fisheries: Ecological traits matter. *Aquatic Conservation: Marine and Freshwater Ecosystems* 29:1324–1335. DOI: 10.1002/aqc.3066.

Žydelis R, Small C, French G. 2013. The incidental catch of seabirds in gillnet fisheries: A global review. *Biological Conservation* 162:76–88. DOI: 10.1016/j.biocon.2013.04.002.

Appendix A Supporting information for Chapter 2

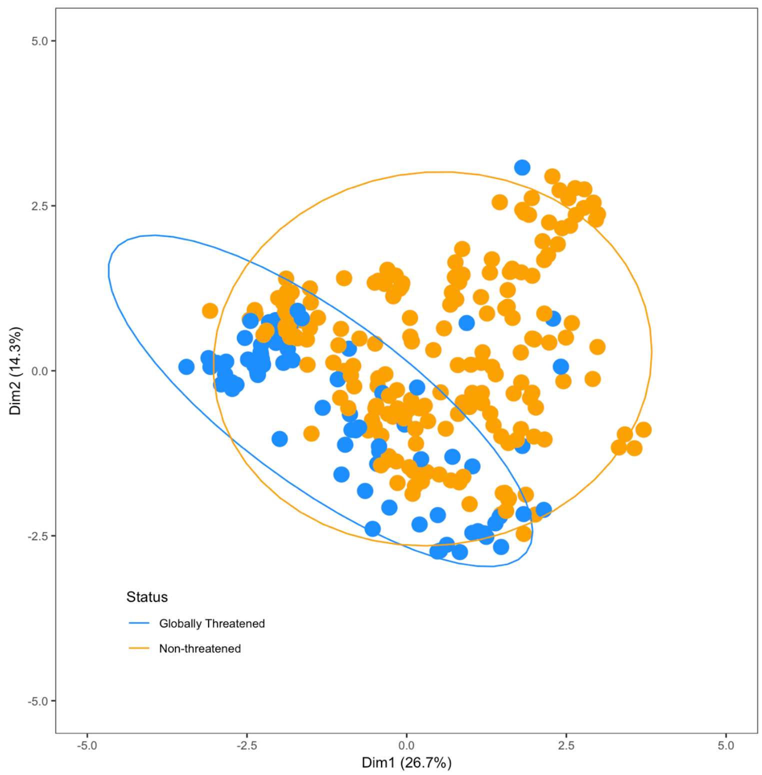


Figure A.1 Mixed data PCA biplot of seabird traits excluding imputed data. Points are the principal component scores of 281 seabird species. Ellipses indicate the 95% confidence intervals for globally threatened (blue) and non-threatened (orange) seabird species.

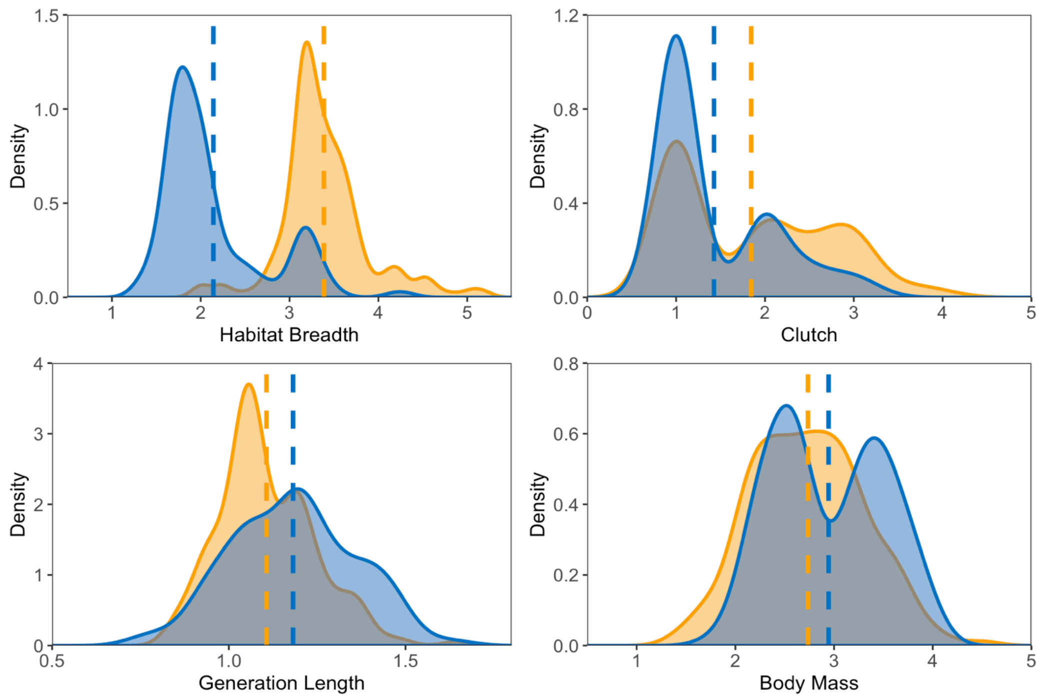


Figure A.2 Distributions of continuous traits excluding imputed data.

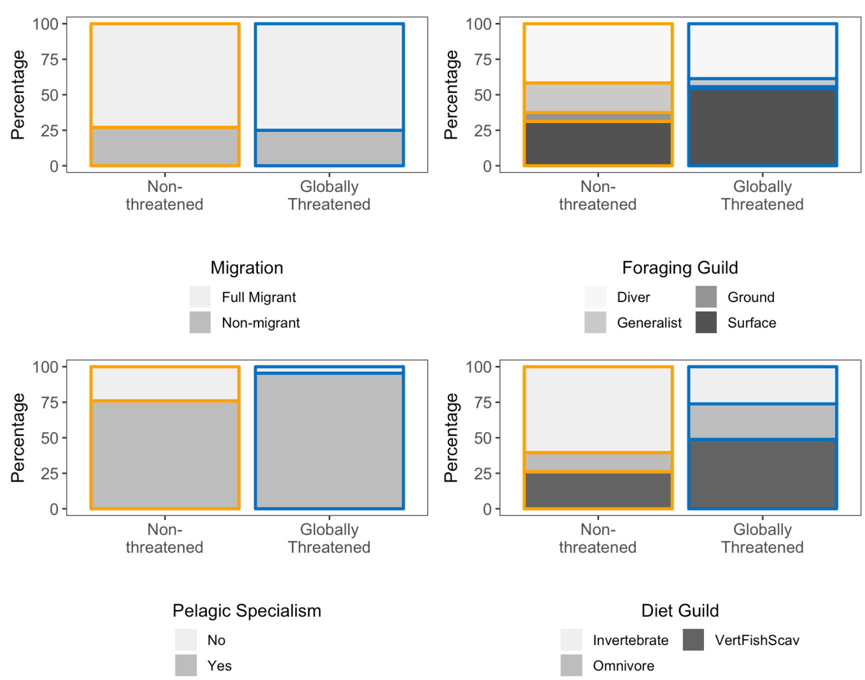


Figure A.3 Proportions of categorical traits excluding imputed data a

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Wilcoxon rank sum test with continuity correction

data:  GT$body_mass_median and NT$body_mass_median
W = 10160, p-value = 0.006509
alternative hypothesis: true location shift is not equal to 0
```

b

```
Wilcoxon rank sum test with continuity correction

data:  GT$hab_breadth and NT$hab_breadth
W = 1236, p-value < 2.2e-16
alternative hypothesis: true location shift is not equal to 0
```

c

```
Wilcoxon rank sum test with continuity correction

data:  GT$GL and NT$GL
W = 10813, p-value = 0.0001685
alternative hypothesis: true location shift is not equal to 0
```

d

```
Wilcoxon rank sum test with continuity correction

data:  GT$clutch and NT$clutch
W = 6200.5, p-value = 0.0001152
alternative hypothesis: true location shift is not equal to 0
```

e

```
Pearson's Chi-squared test

data:  diet
X-squared = 28.368, df = 2, p-value = 6.917e-07
```

f

```
Pearson's Chi-squared test with Yates' continuity correction

data:  migration
X-squared = 0.048859, df = 1, p-value = 0.8251
```

g

```
Pearson's Chi-squared test with Yates' continuity correction

data:  pelagic
X-squared = 14.208, df = 1, p-value = 0.0001637
```

h

```
Pearson's Chi-squared test

data:  foraging
X-squared = 20.644, df = 3, p-value = 0.0001248
```

Figure A.4 R output results from the Mann-Whitney U and Chi-Squared tests which test the difference in the means (Mann-Whitney U) and independence (Chi-Squared) between the non-imputed traits of threatened and non-threatened species. a) body mass; b) habitat breadth; c) generation length d) clutch size; e) diet guild; f) migration; g) pelagic specialism; and h) foraging guild.

```
> hedges_g(body_mass_median ~ Threat , data = traits)
Hedge's g |       95% CI
------------------------
     0.33 | [0.08, 0.58]
> hedges_g(clutch ~ Threat , data = traits)
Hedge's g |         95% CI
--------------------------
    -0.52 | [-0.78, -0.27]
> hedges_g(GL ~ Threat , data = traits)
Hedge's g |       95% CI
------------------------
     0.51 | [0.25, 0.76]
> hedges_g(hab_breadth ~ Threat , data = traits)
Hedge's g |         95% CI
--------------------------
    -2.32 | [-2.63, -2.00]
```

Figure A.5 R output results of the Hedge's g effect size for non-imputed continuous traits

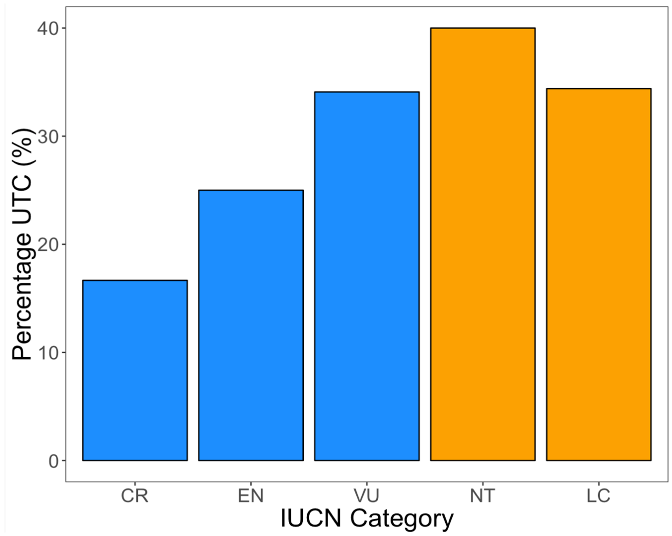

Figure A.6 Proportion of seabird species with non-imputed unique trait combinations for each IUCN category. Orange represents non-threatened categories and blue represents globally threatened categories.

Table A.1 SIMPER output based on non-imputed trait data.

Threat Contrast	Trait	Contribution (%)	Cumulative (%)
Direct vs. Habitat	HAB_medium	8.0	8.0
	non_pelagic	7.4	15.4
	pel_specialist	7.4	22.8
	HAB_small	6.9	29.7
	BM_medium	6.3	36.0
	GL_small	6.0	42.0
	CL_small	5.8	47.8
	Diver	5.0	52.9
Direct vs. No Threats	pel_specialist	9.1	9.1
	non_pelagic	9.1	18.3
	CL_small	8.6	26.9
	fishscav	8.5	35.4
	inverts	7.3	42.7
	HAB_medium	6.4	49.1
	GL_small	6.3	55.4
	CL_medium	5.6	61.0
Habitat vs. No Threats	CL_small	8.5	8.5
	fishscav	7.5	16.0
	inverts	7.5	23.5
	Surface	6.0	29.5
	pel_specialist	5.7	35.2
	non_pelagic	5.7	40.9
	CL_medium	5.4	46.3
	GL_small	5.4	51.7

Appendix B Supporting information for Chapter 3

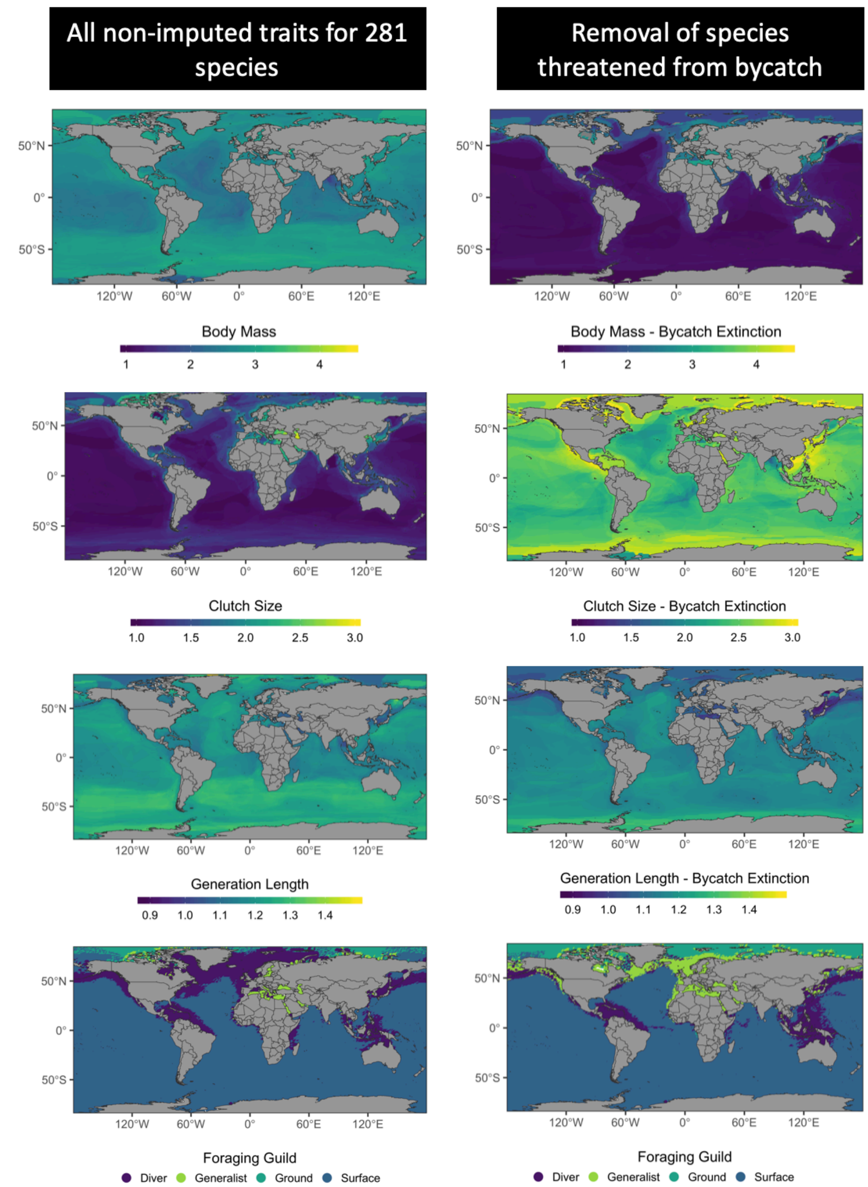

Figure B.1 Spatial conservation of traits through bycatch mitigation using non-imputed data. A-D: present day community weighted mean (CWM) of four traits based on the distributions of 281 seabird species. E-H: community weighted mean of four traits following the removal of species threatened from bycatch. Therefore, the difference represents the shifts in traits that may be prevented through successfully mitigating seabird bycatch. For continuous data, CWM is the mean trait value of all species present *in each 1º grid cell and for categorical data, CWM is the most dominant class per trait within each 1º grid cell.*

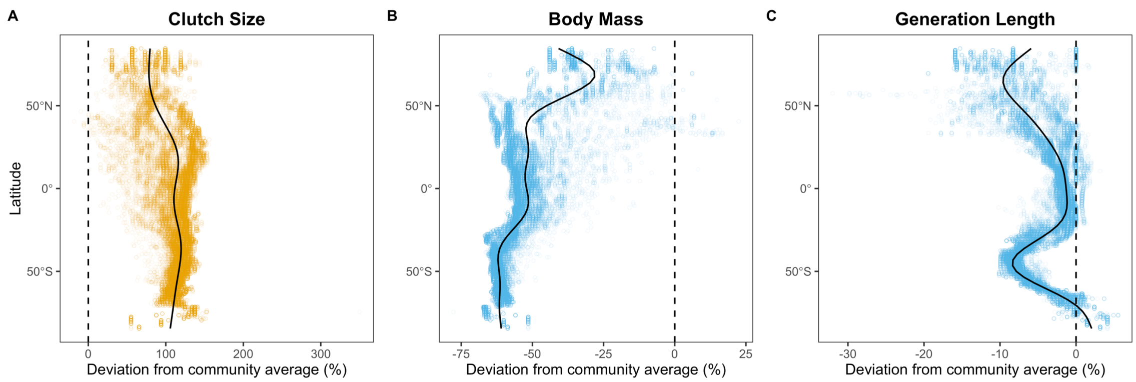

Figure B.2 Shift in community weighted mean (CWM) across latitude using non-imputed data following removal of species threatened from bycatch. Each data point is community weighted mean within a 1º grid cell. Dashed zero line represents the community weighted mean of the total species list (341 species). Solid black lines are fitted generalized additive models (GAM) describing the spatial trends in trait shifts across latitude. Orange represents a significant overall positive shift from the GAM output, and blue a significant overall negative shift in the CWM following removal of species threatened from bycatch.

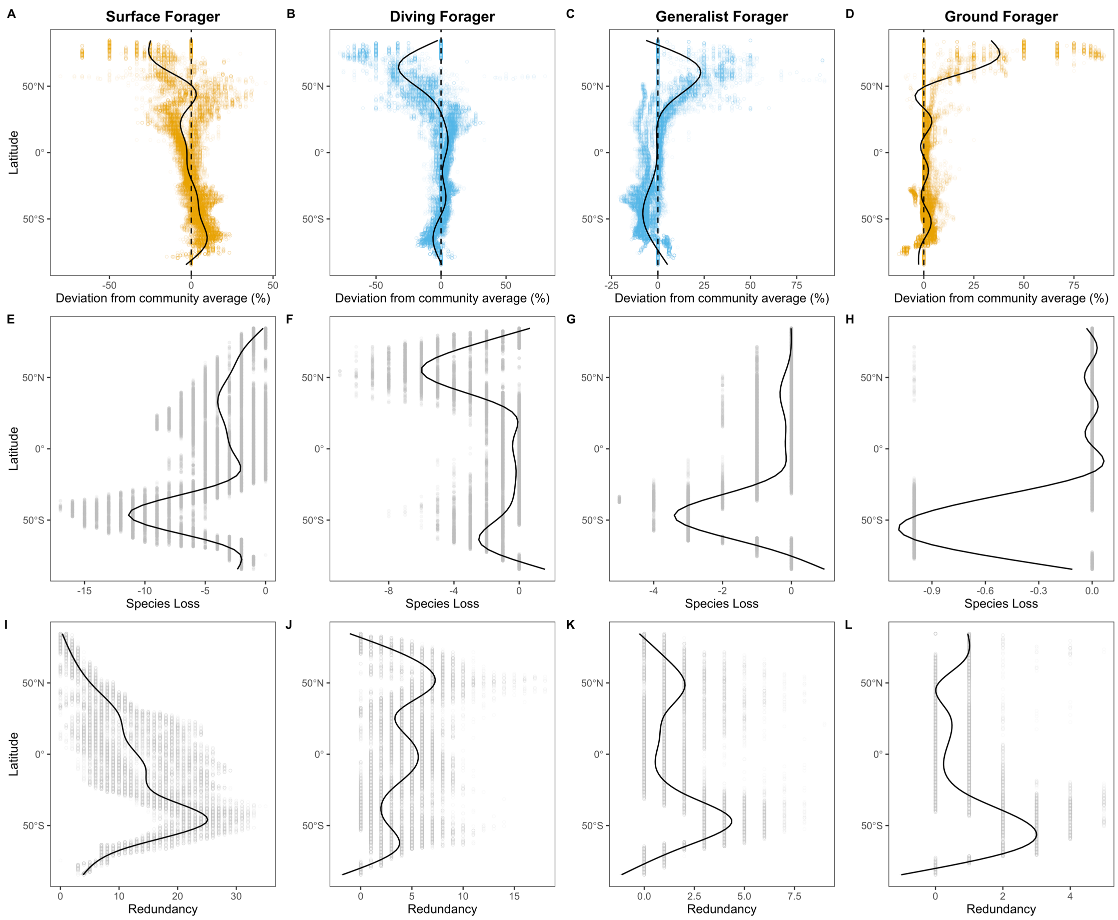

Figure B.3 Latitudinal community shift in foraging guild proportion (A-D) and species loss (E-H) using non-imputed data following removal of species threatened from bycatch, and the redundancy of each foraging guild (I-L).Dashed zero line represents the proportion of each category for the total species list (341 species). Solid black lines are fitted generalized additive models (GAM) describing the spatial trends in trait shifts across latitude. Orange represents a significant overall positive shift from the GAM output, and blue a significant overall negative shift. Species loss (E-H) is the number of species lost per 1º grid cell following the removal of 134 species threatened from bycatch. Redundancy (I-L) is the number of species represented in each foraging guild category, within each 1º grid cell.

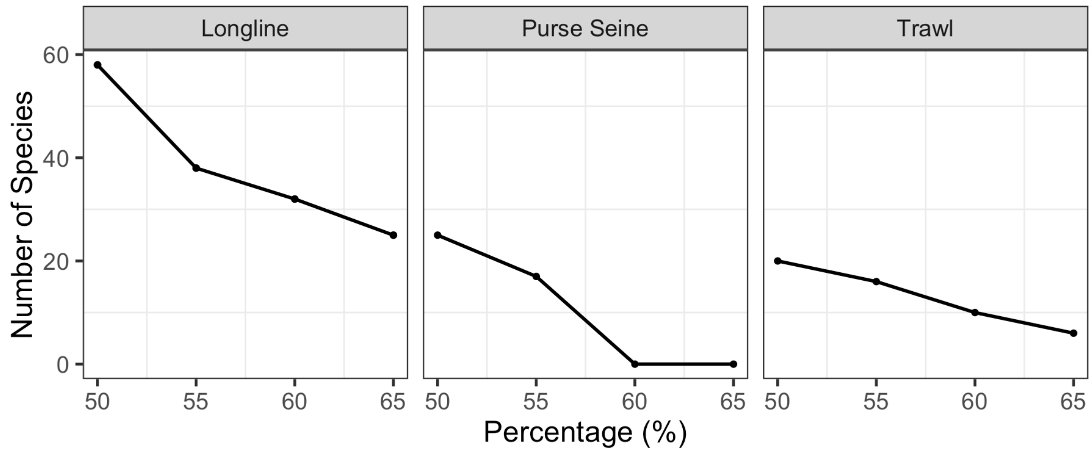

Figure B.4 Sensitivity output for the change in number of species per percentage threshold within the high vulnerability class

Table B.1 Longline vulnerability scores for all seabirds. IUCN indicates whether the species is classified as threatened from bycatch by the International Union for Conservation of Nature.

Gear	Species	Sensitivity	Adaptive	Exposure	Vulnerability	Vulnerability Class	IUCN
Longline	*Pterodroma cervicalis*	0.84	0.85	0.96	0.88	High Vulnerability	NO
Longline	*Ardenna bulleri*	0.84	0.89	0.90	0.88	High Vulnerability	YES
Longline	*Pterodroma solandri*	0.84	0.85	0.88	0.86	High Vulnerability	YES
Longline	*Fregata minor*	0.94	0.72	0.92	0.86	High Vulnerability	NO
Longline	*Phoebastria nigripes*	1.00	0.81	0.75	0.85	High Vulnerability	YES
Longline	*Pseudobulweria rostrata*	0.84	0.81	0.91	0.85	High Vulnerability	NO
Longline	*Ardenna pacifica*	0.84	0.75	0.95	0.85	High Vulnerability	YES
Longline	*Pterodroma heraldica*	0.84	0.72	0.95	0.84	High Vulnerability	NO
Longline	*Pterodroma brevipes*	0.70	0.85	0.94	0.83	High Vulnerability	NO
Longline	*Pterodroma longirostris*	0.70	0.85	0.94	0.83	High Vulnerability	NO
Longline	*Pterodroma neglecta*	0.84	0.72	0.93	0.83	High Vulnerability	NO
Longline	*Fregata ariel*	0.84	0.72	0.90	0.82	High Vulnerability	NO
Longline	*Puffinus bailloni*	0.70	0.77	0.95	0.81	High Vulnerability	NO
Longline	*Diomedea amsterdamensis*	1.00	0.98	0.45	0.81	Potential Future Vulnerability	YES
Longline	*Phoebastria irrorata*	1.00	1.00	0.41	0.80	Potential Future Vulnerability	YES
Longline	*Pterodroma cookii*	0.70	0.85	0.85	0.80	High Vulnerability	NO
Longline	*Pterodroma ultima*	0.84	0.72	0.82	0.79	High Vulnerability	NO
Longline	*Pterodroma pycrofti*	0.70	0.80	0.88	0.79	High Vulnerability	NO
Longline	*Diomedea dabbenena*	1.00	1.00	0.38	0.79	Potential Future Vulnerability	YES
Longline	*Pterodroma leucoptera*	0.70	0.85	0.81	0.79	High Vulnerability	YES
Longline	*Sula sula*	0.73	0.72	0.92	0.79	High Vulnerability	NO
Longline	*Thalassarche chlororhynchos*	0.94	0.97	0.45	0.79	Potential Future Vulnerability	YES
Longline	*Anous stolidus*	0.70	0.72	0.92	0.78	High Vulnerability	NO
Longline	*Gygis alba*	0.70	0.72	0.91	0.78	High Vulnerability	NO
Longline	*Pseudobulweria becki*	0.84	0.97	0.52	0.78	Potential Future Vulnerability	NO
Longline	*Nesofregetta fuliginosa*	0.56	0.91	0.85	0.77	High Vulnerability	NO
Longline	*Fregata aquila*	0.94	0.85	0.52	0.77	Potential Future Vulnerability	YES
Longline	*Phoebastria albatrus*	1.00	0.91	0.38	0.76	Potential Future Vulnerability	YES
Longline	*Phaethon rubricauda*	0.63	0.72	0.95	0.76	High Vulnerability	NO
Longline	*Onychoprion fuscatus*	0.70	0.66	0.93	0.76	High Vulnerability	NO
Longline	*Thalassarche eremita*	1.00	0.91	0.38	0.76	Potential Future Vulnerability	YES
Longline	*Puffinus newelli*	0.84	0.93	0.52	0.76	Potential Future Vulnerability	YES
Longline	*Thalassarche carteri*	0.94	0.97	0.38	0.76	Potential Future Vulnerability	YES
Longline	*Pterodroma nigripennis*	0.70	0.72	0.87	0.76	High Vulnerability	NO

Longline	*Puffinus nativitatis*	0.63	0.75	0.89	0.76	High Vulnerability	NO
Longline	*Anous minutus*	0.70	0.66	0.91	0.76	High Vulnerability	NO
Longline	*Sula dactylatra*	0.73	0.61	0.92	0.76	High Vulnerability	NO
Longline	*Sula leucogaster*	0.73	0.61	0.92	0.76	High Vulnerability	NO
Longline	*Pterodroma phaeopygia*	0.84	0.97	0.45	0.75	Potential Future Vulnerability	YES
Longline	*Bulweria bulwerii*	0.56	0.77	0.93	0.75	High Vulnerability	YES
Longline	*Thalassarche cauta*	1.00	0.84	0.42	0.75	Potential Future Vulnerability	YES
Longline	*Onychoprion lunatus*	0.70	0.66	0.89	0.75	High Vulnerability	NO
Longline	*Pterodroma sandwichensis*	0.84	0.95	0.45	0.75	Potential Future Vulnerability	YES
Longline	*Pterodroma baraui*	0.84	0.91	0.48	0.74	Potential Future Vulnerability	NO
Longline	*Procellaria parkinsoni*	0.84	0.91	0.46	0.74	Potential Future Vulnerability	YES
Longline	*Phaethon lepturus*	0.63	0.66	0.92	0.73	High Vulnerability	NO
Longline	*Hydrobates leucorhous*	0.50	0.85	0.85	0.73	Potential Persisters	NO
Longline	*Pterodroma atrata*	0.84	0.91	0.45	0.73	Potential Future Vulnerability	NO
Longline	*Pseudobulweria aterrima*	0.70	0.97	0.52	0.73	Potential Future Vulnerability	YES
Longline	*Puffinus bryani*	0.70	0.97	0.52	0.73	Potential Future Vulnerability	NO
Longline	*Puffinus bannermani*	0.70	0.97	0.52	0.73	Potential Future Vulnerability	NO
Longline	*Pterodroma arminjoniana*	0.84	0.85	0.48	0.73	Potential Future Vulnerability	NO
Longline	*Pterodroma externa*	0.84	0.85	0.48	0.73	Potential Future Vulnerability	YES
Longline	*Phoebetria fusca*	0.94	0.98	0.26	0.72	Potential Future Vulnerability	YES
Longline	*Ardenna carneipes*	0.45	0.81	0.90	0.72	Potential Persisters	YES
Longline	*Pterodroma madeira*	0.70	0.95	0.52	0.72	Potential Future Vulnerability	NO
Longline	*Morus capensis*	0.73	0.97	0.47	0.72	Potential Future Vulnerability	YES
Longline	*Phoebastria immutabilis*	0.94	0.84	0.38	0.72	Potential Future Vulnerability	YES
Longline	*Diomedea exulans*	1.00	0.91	0.26	0.72	Potential Future Vulnerability	YES
Longline	*Thalassarche salvini*	1.00	0.91	0.26	0.72	Potential Future Vulnerability	YES
Longline	*Diomedea antipodensis*	1.00	0.98	0.17	0.72	Potential Future Vulnerability	YES
Longline	*Diomedea sanfordi*	1.00	0.98	0.17	0.72	Potential Future Vulnerability	YES
Longline	*Pseudobulweria macgillivrayi*	0.70	0.93	0.52	0.72	Potential Future Vulnerability	YES
Longline	*Hydrobates castro*	0.50	0.75	0.89	0.72	Potential Persisters	NO
Longline	*Fregetta grallaria*	0.56	0.72	0.87	0.71	High Vulnerability	NO
Longline	*Pelagodroma marina*	0.56	0.72	0.87	0.71	High Vulnerability	NO
Longline	*Oceanites oceanicus*	0.56	0.72	0.86	0.71	High Vulnerability	NO
Longline	*Pterodroma incerta*	0.84	0.91	0.37	0.71	Potential Future Vulnerability	NO
Longline	*Thalasseus bergii*	0.63	0.66	0.83	0.71	High Vulnerability	NO
Longline	*Fregetta tropica*	0.56	0.72	0.84	0.70	High Vulnerability	NO
Longline	*Pterodroma alba*	0.70	0.91	0.48	0.70	Potential Future Vulnerability	NO
Longline	*Thalassarche impavida*	1.00	0.92	0.17	0.70	Potential Future Vulnerability	YES

Longline	*Procellaria westlandica*	0.94	0.98	0.17	0.70	Potential Future Vulnerability	YES
Longline	*Thalassarche steadi*	1.00	0.84	0.26	0.70	Potential Future Vulnerability	YES
Longline	*Pterodroma cahow*	0.70	0.91	0.47	0.69	Potential Future Vulnerability	NO
Longline	*Calonectris leucomelas*	0.84	0.81	0.42	0.69	Potential Future Vulnerability	YES
Longline	*Thalassarche chrysostoma*	1.00	0.98	0.10	0.69	Potential Future Vulnerability	YES
Longline	*Pterodroma deserta*	0.70	0.89	0.48	0.69	Potential Future Vulnerability	NO
Longline	*Ardenna grisea*	0.45	0.84	0.77	0.69	Potential Persisters	YES
Longline	*Puffinus auricularis*	0.84	0.97	0.25	0.69	Potential Future Vulnerability	NO
Longline	*Papasula abbotti*	0.73	0.91	0.41	0.68	Potential Future Vulnerability	YES
Longline	*Ardenna tenuirostris*	0.45	0.75	0.83	0.68	Potential Persisters	YES
Longline	*Pterodroma feae*	0.70	0.81	0.52	0.68	Potential Future Vulnerability	NO
Longline	*Thalassarche melanophris*	1.00	0.77	0.26	0.68	Potential Future Vulnerability	YES
Longline	*Diomedea epomophora*	1.00	0.92	0.10	0.67	Potential Future Vulnerability	YES
Longline	*Pterodroma defilippiana*	0.70	0.85	0.45	0.67	Potential Future Vulnerability	NO
Longline	*Fregetta maoriana*	0.56	0.93	0.52	0.67	Potential Future Vulnerability	NO
Longline	*Pterodroma hasitata*	0.70	0.91	0.37	0.66	Potential Future Vulnerability	NO
Longline	*Pterodroma inexpectata*	0.45	0.78	0.75	0.66	Potential Persisters	NO
Longline	*Anous ceruleus*	0.56	0.58	0.85	0.66	High Vulnerability	NO
Longline	*Fregata andrewsi*	0.94	0.93	0.10	0.66	Potential Future Vulnerability	YES
Longline	*Eudyptes moseleyi*	0.94	0.71	0.32	0.66	Potential Future Vulnerability	YES
Longline	*Puffinus huttoni*	0.63	0.95	0.37	0.65	Potential Future Vulnerability	YES
Longline	*Bulweria fallax*	0.70	0.84	0.41	0.65	Potential Future Vulnerability	NO
Longline	*Procellaria conspicillata*	0.55	0.92	0.47	0.65	Potential Future Vulnerability	YES
Longline	*Fregata magnificens*	0.94	0.75	0.25	0.65	Potential Future Vulnerability	NO
Longline	*Gygis microrhyncha*	0.70	0.72	0.52	0.64	Potential Future Vulnerability	NO
Longline	*Thalassarche bulleri*	0.94	0.81	0.17	0.64	Potential Future Vulnerability	YES
Longline	*Puffinus mauretanicus*	0.63	0.97	0.32	0.64	Potential Future Vulnerability	YES
Longline	*Phalacrocorax capensis*	0.73	0.67	0.52	0.64	Potential Future Vulnerability	YES
Longline	*Pterodroma magentae*	0.84	0.97	0.10	0.64	Potential Future Vulnerability	NO
Longline	*Hydrobates monteiroi*	0.50	0.89	0.52	0.64	Low Vulnerability	NO
Longline	*Pterodroma hypoleuca*	0.70	0.72	0.48	0.63	Potential Future Vulnerability	NO
Longline	*Puffinus heinrothi*	0.49	0.89	0.52	0.63	Low Vulnerability	NO
Longline	*Spheniscus demersus*	0.79	0.63	0.47	0.63	Potential Future Vulnerability	YES
Longline	*Morus serrator*	0.73	0.77	0.37	0.63	Potential Future Vulnerability	YES
Longline	*Pterodroma gouldi*	0.84	0.72	0.32	0.63	Potential Future Vulnerability	NO
Longline	*Daption capense*	0.84	0.77	0.26	0.62	Potential Future Vulnerability	NO
Longline	*Catharacta skua*	0.94	0.61	0.32	0.62	Potential Future Vulnerability	YES
Longline	*Megadyptes antipodes*	0.79	0.71	0.37	0.62	Potential Future Vulnerability	YES

Longline	*Phoebetria palpebrata*	0.94	0.85	0.07	0.62	Potential Future Vulnerability	YES
Longline	*Puffinus yelkouan*	0.63	0.89	0.32	0.61	Potential Future Vulnerability	YES
Longline	*Sterna sumatrana*	0.49	0.52	0.83	0.61	Low Vulnerability	NO
Longline	*Pterodroma macroptera*	0.84	0.72	0.26	0.60	Potential Future Vulnerability	NO
Longline	*Hydrobates matsudairae*	0.50	0.85	0.46	0.60	Low Vulnerability	NO
Longline	*Anous tenuirostris*	0.70	0.66	0.45	0.60	Potential Future Vulnerability	NO
Longline	*Pterodroma axillaris*	0.70	0.85	0.25	0.60	Potential Future Vulnerability	NO
Longline	*Phalacrocorax neglectus*	0.73	0.55	0.52	0.60	Potential Future Vulnerability	YES
Longline	*Fulmarus glacialoides*	0.84	0.77	0.18	0.60	Potential Future Vulnerability	NO
Longline	*Larus atlanticus*	0.84	0.58	0.37	0.60	Potential Future Vulnerability	YES
Longline	*Calonectris edwardsii*	0.45	0.81	0.52	0.59	Low Vulnerability	NO
Longline	*Puffinus persicus*	0.70	0.75	0.32	0.59	Potential Future Vulnerability	NO
Longline	*Larus crassirostris*	0.84	0.52	0.41	0.59	Low Vulnerability	NO
Longline	*Larus audouinii*	0.84	0.51	0.41	0.59	Low Vulnerability	YES
Longline	*Puffinus puffinus*	0.63	0.75	0.38	0.59	Potential Future Vulnerability	NO
Longline	*Hydrobates markhami*	0.50	0.81	0.45	0.59	Low Vulnerability	NO
Longline	*Leucocarbo carunculatus*	0.73	0.57	0.45	0.58	Potential Future Vulnerability	YES
Longline	*Morus bassanus*	0.73	0.77	0.25	0.58	Potential Future Vulnerability	YES
Longline	*Sternula balaenarum*	0.56	0.71	0.47	0.58	Potential Future Vulnerability	YES
Longline	*Pterodroma mollis*	0.70	0.72	0.33	0.58	Potential Future Vulnerability	NO
Longline	*Onychoprion anaethetus*	0.70	0.66	0.38	0.58	Potential Future Vulnerability	NO
Longline	*Hydrobates tristrami*	0.50	0.72	0.52	0.58	Low Vulnerability	NO
Longline	*Fulmarus glacialis*	0.84	0.78	0.10	0.58	Potential Future Vulnerability	YES
Longline	*Procellaria aequinoctialis*	0.55	0.91	0.26	0.57	Potential Future Vulnerability	YES
Longline	*Fratercula arctica*	0.63	0.91	0.17	0.57	Potential Future Vulnerability	YES
Longline	*Puffinus lherminieri*	0.49	0.77	0.45	0.57	Low Vulnerability	NO
Longline	*Leucocarbo chalconotus*	0.73	0.53	0.45	0.57	Low Vulnerability	YES
Longline	*Hydrobates pelagicus*	0.50	0.72	0.48	0.57	Low Vulnerability	NO
Longline	*Aphrodroma brevirostris*	0.84	0.75	0.10	0.57	Potential Future Vulnerability	NO
Longline	*Hydrobates homochroa*	0.50	0.95	0.25	0.56	Low Vulnerability	NO
Longline	*Calonectris borealis*	0.45	0.75	0.48	0.56	Low Vulnerability	YES
Longline	*Aptenodytes forsteri*	0.79	0.84	0.07	0.56	Potential Future Vulnerability	NO
Longline	*Calonectris diomedea*	0.45	0.75	0.48	0.56	Low Vulnerability	YES
Longline	*Pachyptila vittata*	0.70	0.66	0.33	0.56	Potential Future Vulnerability	NO
Longline	*Eudyptes pachyrhynchus*	0.79	0.57	0.32	0.56	Potential Future Vulnerability	YES
Longline	*Stercorarius pomarinus*	0.34	0.58	0.75	0.56	Potential Persisters	NO
Longline	*Pachyptila belcheri*	0.70	0.72	0.25	0.56	Potential Future Vulnerability	NO
Longline	*Ardenna creatopus*	0.45	0.89	0.32	0.55	Low Vulnerability	YES

Longline	*Phaethon aethereus*	0.63	0.66	0.37	0.55	Potential Future Vulnerability	NO
Longline	*Pterodroma lessonii*	0.84	0.72	0.10	0.55	Potential Future Vulnerability	NO
Longline	*Rissa brevirostris*	0.63	0.85	0.17	0.55	Potential Future Vulnerability	YES
Longline	*Hydrobates monorhis*	0.50	0.78	0.37	0.55	Low Vulnerability	NO
Longline	*Nannopterum harrisi*	0.79	0.61	0.25	0.55	Potential Future Vulnerability	YES
Longline	*Leucocarbo onslowi*	0.73	0.59	0.32	0.55	Potential Future Vulnerability	YES
Longline	*Hydrobates hornbyi*	0.50	0.81	0.32	0.54	Low Vulnerability	NO
Longline	*Ardenna gravis*	0.45	0.75	0.42	0.54	Low Vulnerability	YES
Longline	*Thalassoica antarctica*	0.84	0.72	0.07	0.54	Potential Future Vulnerability	NO
Longline	*Eudyptes robustus*	0.79	0.66	0.17	0.54	Potential Future Vulnerability	YES
Longline	*Spheniscus humboldti*	0.79	0.66	0.17	0.54	Potential Future Vulnerability	YES
Longline	*Phalacrocorax featherstoni*	0.73	0.57	0.32	0.54	Potential Future Vulnerability	YES
Longline	*Pelecanus thagus*	0.79	0.57	0.25	0.54	Potential Future Vulnerability	YES
Longline	*Anous albivittus*	0.56	0.58	0.47	0.54	Potential Future Vulnerability	NO
Longline	*Pachyptila salvini*	0.70	0.66	0.25	0.54	Potential Future Vulnerability	NO
Longline	*Rissa tridactyla*	0.63	0.71	0.26	0.53	Potential Future Vulnerability	YES
Longline	*Hydrobates tethys*	0.50	0.72	0.37	0.53	Low Vulnerability	NO
Longline	*Larus pacificus*	0.94	0.48	0.17	0.53	Low Vulnerability	NO
Longline	*Spheniscus mendiculus*	0.73	0.61	0.25	0.53	Potential Future Vulnerability	YES
Longline	*Pelecanoides garnotii*	0.49	0.85	0.25	0.53	Low Vulnerability	YES
Longline	*Alca torda*	0.63	0.78	0.17	0.53	Potential Future Vulnerability	YES
Longline	*Fratercula cirrhata*	0.63	0.77	0.17	0.53	Potential Future Vulnerability	YES
Longline	*Procellaria cinerea*	0.55	0.84	0.18	0.53	Potential Future Vulnerability	YES
Longline	*Aptenodytes patagonicus*	0.79	0.72	0.07	0.52	Potential Future Vulnerability	NO
Longline	*Thalasseus bernsteini*	0.70	0.69	0.17	0.52	Potential Future Vulnerability	YES
Longline	*Sternula lorata*	0.56	0.63	0.37	0.52	Potential Future Vulnerability	YES
Longline	*Puffinus assimilis*	0.49	0.75	0.32	0.52	Low Vulnerability	NO
Longline	*Puffinus elegans*	0.49	0.75	0.32	0.52	Low Vulnerability	NO
Longline	*Puffinus gavia*	0.49	0.75	0.32	0.52	Low Vulnerability	YES
Longline	*Puffinus subalaris*	0.49	0.75	0.32	0.52	Low Vulnerability	NO
Longline	*Eudyptes sclateri*	0.79	0.71	0.07	0.52	Potential Future Vulnerability	YES
Longline	*Synthliboramphus wumizusume*	0.49	0.66	0.41	0.52	Low Vulnerability	YES
Longline	*Phalacrocorax punctatus*	0.73	0.37	0.45	0.52	Low Vulnerability	NO
Longline	*Macronectes halli*	0.61	0.75	0.18	0.51	Potential Future Vulnerability	YES
Longline	*Pagodroma nivea*	0.70	0.77	0.07	0.51	Potential Future Vulnerability	NO
Longline	*Pachyptila desolata*	0.70	0.66	0.18	0.51	Potential Future Vulnerability	NO
Longline	*Hydrobates melania*	0.50	0.72	0.32	0.51	Low Vulnerability	NO
Longline	*Larus modestus*	0.84	0.52	0.17	0.51	Low Vulnerability	NO

Longline	*Spheniscus magellanicus*	0.79	0.50	0.25	0.51	Low Vulnerability	YES
Longline	*Creagrus furcatus*	0.45	0.75	0.32	0.51	Low Vulnerability	NO
Longline	*Uria aalge*	0.63	0.72	0.17	0.51	Potential Future Vulnerability	YES
Longline	*Uria lomvia*	0.63	0.72	0.17	0.51	Potential Future Vulnerability	YES
Longline	*Phalacrocorax capillatus*	0.73	0.37	0.41	0.51	Low Vulnerability	NO
Longline	*Eudyptes chrysolophus*	0.79	0.66	0.07	0.50	Potential Future Vulnerability	YES
Longline	*Fratercula corniculata*	0.63	0.77	0.10	0.50	Potential Future Vulnerability	YES
Longline	*Pelecanus conspicillatus*	0.79	0.61	0.10	0.50	Potential Future Vulnerability	NO
Longline	*Eudyptes chrysocome*	0.73	0.66	0.10	0.50	Potential Future Vulnerability	NO
Longline	*Pelecanus occidentalis*	0.79	0.51	0.17	0.49	Low Vulnerability	YES
Longline	*Thalasseus bengalensis*	0.49	0.66	0.33	0.49	Low Vulnerability	NO
Longline	*Hydrobates furcatus*	0.50	0.72	0.25	0.49	Low Vulnerability	NO
Longline	*Pelecanus philippensis*	0.79	0.57	0.10	0.49	Potential Future Vulnerability	YES
Longline	*Sternula nereis*	0.56	0.66	0.25	0.49	Potential Future Vulnerability	NO
Longline	*Halobaena caerulea*	0.70	0.66	0.10	0.49	Potential Future Vulnerability	NO
Longline	*Synthliboramphus scrippsi*	0.70	0.66	0.10	0.49	Potential Future Vulnerability	YES
Longline	*Cerorhinca monocerata*	0.63	0.58	0.25	0.49	Potential Future Vulnerability	YES
Longline	*Macronectes giganteus*	0.50	0.77	0.18	0.48	Low Vulnerability	YES
Longline	*Larosterna inca*	0.70	0.58	0.17	0.48	Potential Future Vulnerability	YES
Longline	*Eudyptula minor*	0.73	0.40	0.32	0.48	Low Vulnerability	YES
Longline	*Garrodia nereis*	0.56	0.72	0.17	0.48	Potential Future Vulnerability	NO
Longline	*Sterna striata*	0.49	0.58	0.37	0.48	Low Vulnerability	NO
Longline	*Pelecanus erythrorhynchos*	0.79	0.58	0.07	0.48	Potential Future Vulnerability	NO
Longline	*Pelecanus onocrotalus*	0.79	0.58	0.07	0.48	Potential Future Vulnerability	NO
Longline	*Pelecanus rufescens*	0.79	0.58	0.07	0.48	Potential Future Vulnerability	NO
Longline	*Eudyptes schlegeli*	0.79	0.64	0.00	0.47	Potential Future Vulnerability	YES
Longline	*Onychoprion aleuticus*	0.70	0.66	0.07	0.47	Potential Future Vulnerability	NO
Longline	*Larus hemprichii*	0.84	0.48	0.10	0.47	Low Vulnerability	NO
Longline	*Poikilocarbo gaimardi*	0.73	0.43	0.25	0.47	Low Vulnerability	YES
Longline	*Brachyramphus marmoratus*	0.49	0.85	0.07	0.47	Low Vulnerability	YES
Longline	*Thalasseus maximus*	0.63	0.52	0.25	0.47	Low Vulnerability	NO
Longline	*Pelecanoides urinatrix*	0.49	0.66	0.25	0.47	Low Vulnerability	NO
Longline	*Sterna dougallii*	0.49	0.52	0.38	0.46	Low Vulnerability	YES
Longline	*Thalasseus elegans*	0.49	0.72	0.17	0.46	Low Vulnerability	YES
Longline	*Alle alle*	0.49	0.72	0.17	0.46	Low Vulnerability	YES
Longline	*Sula variegata*	0.73	0.48	0.17	0.46	Low Vulnerability	NO
Longline	*Synthliboramphus hypoleucus*	0.49	0.71	0.17	0.46	Low Vulnerability	YES
Longline	*Pygoscelis adeliae*	0.79	0.52	0.07	0.46	Low Vulnerability	YES

Longline	*Puffinus opisthomelas*	0.45	0.81	0.10	0.46	Low Vulnerability	YES
Longline	*Microcarbo coronatus*	0.45	0.40	0.52	0.46	Low Vulnerability	NO
Longline	*Pelecanus crispus*	0.79	0.52	0.07	0.46	Low Vulnerability	YES
Longline	*Phalacrocorax nigrogularis*	0.73	0.53	0.10	0.45	Low Vulnerability	YES
Longline	*Larus thayeri*	0.84	0.46	0.07	0.45	Low Vulnerability	NO
Longline	*Rynchops albicollis*	0.70	0.59	0.07	0.45	Potential Future Vulnerability	NO
Longline	*Aethia psittacula*	0.49	0.54	0.32	0.45	Low Vulnerability	NO
Longline	*Leucocarbo magellanicus*	0.73	0.37	0.25	0.45	Low Vulnerability	YES
Longline	*Larus hartlaubii*	0.31	0.52	0.52	0.45	Low Vulnerability	NO
Longline	*Sterna paradisaea*	0.70	0.58	0.07	0.45	Potential Future Vulnerability	YES
Longline	*Sula nebouxii*	0.73	0.44	0.17	0.45	Low Vulnerability	NO
Longline	*Catharacta chilensis*	0.55	0.61	0.17	0.45	Potential Future Vulnerability	YES
Longline	*Larus bulleri*	0.20	0.71	0.41	0.44	Low Vulnerability	NO
Longline	*Synthliboramphus craveri*	0.49	0.66	0.17	0.44	Low Vulnerability	YES
Longline	*Pelecanoides magellani*	0.49	0.66	0.17	0.44	Low Vulnerability	NO
Longline	*Hydrobates microsoma*	0.50	0.72	0.10	0.44	Low Vulnerability	NO
Longline	*Larus leucophthalmus*	0.84	0.48	0.00	0.44	Low Vulnerability	YES
Longline	*Brachyramphus perdix*	0.49	0.72	0.10	0.44	Low Vulnerability	YES
Longline	*Sterna virgata*	0.49	0.72	0.10	0.44	Low Vulnerability	NO
Longline	*Larus fuliginosus*	0.45	0.53	0.32	0.43	Low Vulnerability	YES
Longline	*Leucocarbo campbelli*	0.73	0.57	0.00	0.43	Potential Future Vulnerability	NO
Longline	*Rynchops flavirostris*	0.70	0.54	0.07	0.43	Low Vulnerability	YES
Longline	*Pygoscelis antarcticus*	0.79	0.44	0.07	0.43	Low Vulnerability	YES
Longline	*Pachyptila turtur*	0.31	0.66	0.32	0.43	Low Vulnerability	NO
Longline	*Leucocarbo atriceps*	0.73	0.46	0.10	0.43	Low Vulnerability	YES
Longline	*Brachyramphus brevirostris*	0.49	0.72	0.07	0.42	Low Vulnerability	YES
Longline	*Catharacta maccormicki*	0.55	0.61	0.10	0.42	Potential Future Vulnerability	NO
Longline	*Phalacrocorax fuscescens*	0.73	0.44	0.10	0.42	Low Vulnerability	NO
Longline	*Sula granti*	0.73	0.44	0.10	0.42	Low Vulnerability	NO
Longline	*Leucocarbo ranfurlyi*	0.73	0.53	0.00	0.42	Low Vulnerability	NO
Longline	*Thalasseus sandvicensis*	0.49	0.52	0.25	0.42	Low Vulnerability	NO
Longline	*Pygoscelis papua*	0.79	0.40	0.07	0.42	Low Vulnerability	YES
Longline	*Larus michahellis*	0.55	0.46	0.25	0.42	Low Vulnerability	NO
Longline	*Larus schistisagus*	0.55	0.46	0.25	0.42	Low Vulnerability	NO
Longline	*Urile penicillatus*	0.73	0.46	0.07	0.42	Low Vulnerability	NO
Longline	*Pelecanoides georgicus*	0.49	0.66	0.10	0.42	Low Vulnerability	NO
Longline	*Cepphus carbo*	0.63	0.44	0.17	0.41	Low Vulnerability	YES
Longline	*Gulosus aristotelis*	0.73	0.34	0.17	0.41	Low Vulnerability	YES

Longline	*Leucocarbo colensoi*	0.73	0.51	0.00	0.41	Low Vulnerability	NO
Longline	*Phalacrocorax carbo*	0.73	0.41	0.10	0.41	Low Vulnerability	YES
Longline	*Urile pelagicus*	0.73	0.33	0.17	0.41	Low Vulnerability	NO
Longline	*Catharacta antarctica*	0.44	0.61	0.17	0.41	Low Vulnerability	NO
Longline	*Cepphus grylle*	0.63	0.52	0.07	0.40	Low Vulnerability	YES
Longline	*Sterna hirundinacea*	0.49	0.48	0.25	0.40	Low Vulnerability	NO
Longline	*Sternula saundersi*	0.56	0.48	0.17	0.40	Low Vulnerability	NO
Longline	*Ptychoramphus aleuticus*	0.49	0.60	0.10	0.40	Low Vulnerability	YES
Longline	*Chlidonias albostriatus*	0.17	0.65	0.37	0.40	Low Vulnerability	NO
Longline	*Sterna vittata*	0.49	0.52	0.17	0.40	Low Vulnerability	NO
Longline	*Oceanites gracilis*	0.50	0.43	0.25	0.39	Low Vulnerability	NO
Longline	*Larus dominicanus*	0.45	0.48	0.25	0.39	Low Vulnerability	NO
Longline	*Rynchops niger*	0.70	0.41	0.07	0.39	Low Vulnerability	NO
Longline	*Phalacrocorax varius*	0.73	0.34	0.10	0.39	Low Vulnerability	NO
Longline	*Urile urile*	0.73	0.34	0.10	0.39	Low Vulnerability	NO
Longline	*Aethia cristatella*	0.49	0.58	0.10	0.39	Low Vulnerability	NO
Longline	*Larus smithsonianus*	0.55	0.51	0.10	0.39	Low Vulnerability	YES
Longline	*Larus belcheri*	0.45	0.46	0.25	0.39	Low Vulnerability	NO
Longline	*Pachyptila crassirostris*	0.31	0.66	0.17	0.38	Low Vulnerability	NO
Longline	*Larus fuscus*	0.45	0.51	0.17	0.38	Low Vulnerability	NO
Longline	*Rhodostethia rosea*	0.70	0.37	0.07	0.38	Low Vulnerability	NO
Longline	*Synthliboramphus antiquus*	0.49	0.40	0.25	0.38	Low Vulnerability	NO
Longline	*Cepphus columba*	0.63	0.44	0.07	0.38	Low Vulnerability	YES
Longline	*Nannopterum auritus*	0.73	0.34	0.07	0.38	Low Vulnerability	NO
Longline	*Nannopterum brasilianus*	0.73	0.34	0.07	0.38	Low Vulnerability	NO
Longline	*Larus argentatus*	0.55	0.51	0.07	0.38	Low Vulnerability	YES
Longline	*Larus glaucescens*	0.55	0.51	0.07	0.38	Low Vulnerability	NO
Longline	*Larus ichthyaetus*	0.55	0.48	0.10	0.38	Low Vulnerability	NO
Longline	*Sterna repressa*	0.35	0.52	0.25	0.37	Low Vulnerability	NO
Longline	*Larus cirrocephalus*	0.45	0.48	0.17	0.37	Low Vulnerability	NO
Longline	*Aethia pygmaea*	0.49	0.54	0.07	0.37	Low Vulnerability	NO
Longline	*Stercorarius parasiticus*	0.34	0.58	0.17	0.36	Low Vulnerability	NO
Longline	*Larus heermanni*	0.45	0.54	0.10	0.36	Low Vulnerability	YES
Longline	*Sterna trudeaui*	0.49	0.42	0.17	0.36	Low Vulnerability	NO
Longline	*Larus cachinnans*	0.55	0.46	0.07	0.36	Low Vulnerability	NO
Longline	*Larus hyperboreus*	0.55	0.46	0.07	0.36	Low Vulnerability	NO
Longline	*Sterna aurantia*	0.49	0.52	0.07	0.36	Low Vulnerability	NO
Longline	*Larus armenicus*	0.45	0.52	0.10	0.36	Low Vulnerability	NO

Longline	*Sterna hirundo*	0.49	0.48	0.10	0.36	Low Vulnerability	NO
Longline	*Sterna acuticauda*	0.31	0.65	0.10	0.35	Low Vulnerability	YES
Longline	*Phalacrocorax fuscicollis*	0.63	0.33	0.10	0.35	Low Vulnerability	NO
Longline	*Phalacrocorax sulcirostris*	0.63	0.33	0.10	0.35	Low Vulnerability	NO
Longline	*Larus relictus*	0.45	0.53	0.07	0.35	Low Vulnerability	NO
Longline	*Hydroprogne caspia*	0.45	0.48	0.10	0.34	Low Vulnerability	NO
Longline	*Larus brunnicephalus*	0.45	0.48	0.10	0.34	Low Vulnerability	NO
Longline	*Larus melanocephalus*	0.31	0.46	0.25	0.34	Low Vulnerability	NO
Longline	*Sterna forsteri*	0.49	0.46	0.07	0.34	Low Vulnerability	NO
Longline	*Larus livens*	0.55	0.46	0.00	0.34	Low Vulnerability	NO
Longline	*Chlidonias niger*	0.56	0.37	0.07	0.33	Low Vulnerability	NO
Longline	*Larus marinus*	0.44	0.46	0.10	0.33	Low Vulnerability	YES
Longline	*Larus glaucoides*	0.45	0.48	0.07	0.33	Low Vulnerability	NO
Longline	*Larus serranus*	0.45	0.48	0.07	0.33	Low Vulnerability	NO
Longline	*Aethia pusilla*	0.35	0.54	0.10	0.33	Low Vulnerability	NO
Longline	*Pagophila eburnea*	0.34	0.58	0.07	0.33	Low Vulnerability	NO
Longline	*Larus novaehollandiae*	0.31	0.48	0.17	0.32	Low Vulnerability	NO
Longline	*Larus occidentalis*	0.34	0.51	0.10	0.32	Low Vulnerability	NO
Longline	*Larus genei*	0.31	0.46	0.17	0.31	Low Vulnerability	NO
Longline	*Oceanites pincoyae*	0.50	0.43	0.00	0.31	Low Vulnerability	NO
Longline	*Larus canus*	0.45	0.37	0.10	0.31	Low Vulnerability	NO
Longline	*Larus maculipennis*	0.34	0.46	0.10	0.30	Low Vulnerability	NO
Longline	*Microcarbo niger*	0.45	0.37	0.07	0.30	Low Vulnerability	NO
Longline	*Microcarbo africanus*	0.45	0.33	0.10	0.29	Low Vulnerability	YES
Longline	*Microcarbo melanoleucos*	0.45	0.33	0.10	0.29	Low Vulnerability	NO
Longline	*Hydrocoloeus minutus*	0.31	0.46	0.10	0.29	Low Vulnerability	NO
Longline	*Larus atricilla*	0.31	0.46	0.10	0.29	Low Vulnerability	NO
Longline	*Larus californicus*	0.34	0.46	0.07	0.29	Low Vulnerability	NO
Longline	*Larus delawarensis*	0.34	0.46	0.07	0.29	Low Vulnerability	NO
Longline	*Larus ridibundus*	0.31	0.37	0.17	0.29	Low Vulnerability	NO
Longline	*Phaetusa simplex*	0.31	0.48	0.07	0.28	Low Vulnerability	NO
Longline	*Larus philadelphia*	0.31	0.46	0.07	0.28	Low Vulnerability	NO
Longline	*Larus pipixcan*	0.31	0.46	0.07	0.28	Low Vulnerability	NO
Longline	*Gelochelidon nilotica*	0.31	0.42	0.10	0.28	Low Vulnerability	NO
Longline	*Sternula albifrons*	0.17	0.48	0.17	0.27	Low Vulnerability	NO
Longline	*Stercorarius longicaudus*	0.20	0.52	0.07	0.26	Low Vulnerability	NO
Longline	*Sternula antillarum*	0.17	0.48	0.10	0.25	Low Vulnerability	NO
Longline	*Xema sabini*	0.20	0.36	0.17	0.25	Low Vulnerability	NO

Longline	*Sternula superciliaris*	0.17	0.48	0.07	0.24	Low Vulnerability	NO
Longline	*Chlidonias hybrida*	0.17	0.37	0.07	0.20	Low Vulnerability	NO
Longline	*Chlidonias leucopterus*	0.17	0.37	0.07	0.20	Low Vulnerability	NO

Table B.2 Trawl vulnerability scores for all seabirds. IUCN indicates whether the species is classified as threatened from bycatch by the International Union for Conservation of Nature.

Gear	Species	Sensitivity	Adaptive	Exposure	Vulnerability	Vulnerability Class	IUCN
Trawl	*Fulmarus glacialis*	0.84	0.78	0.86	0.83	High Vulnerability	YES
Trawl	*Puffinus mauretanicus*	0.63	0.97	0.89	0.83	High Vulnerability	YES
Trawl	*Phoebastria albatrus*	1.00	0.91	0.57	0.83	High Vulnerability	YES
Trawl	*Fratercula arctica*	0.63	0.91	0.89	0.81	High Vulnerability	YES
Trawl	*Catharacta skua*	0.94	0.61	0.86	0.81	High Vulnerability	YES
Trawl	*Morus bassanus*	0.73	0.77	0.89	0.80	High Vulnerability	YES
Trawl	*Puffinus yelkouan*	0.63	0.89	0.82	0.78	High Vulnerability	YES
Trawl	*Alca torda*	0.63	0.78	0.89	0.77	High Vulnerability	YES
Trawl	*Phoebastria irrorata*	1.00	1.00	0.29	0.76	Potential Future Vulnerability	YES
Trawl	*Calonectris leucomelas*	0.84	0.81	0.61	0.75	High Vulnerability	YES
Trawl	*Rissa tridactyla*	0.63	0.71	0.88	0.74	High Vulnerability	YES
Trawl	*Larus crassirostris*	0.84	0.52	0.87	0.74	Potential Adapters	NO
Trawl	*Uria aalge*	0.63	0.72	0.86	0.74	High Vulnerability	YES
Trawl	*Morus capensis*	0.73	0.97	0.42	0.71	Potential Future Vulnerability	YES
Trawl	*Puffinus puffinus*	0.63	0.75	0.73	0.70	High Vulnerability	NO
Trawl	*Procellaria westlandica*	0.94	0.98	0.17	0.70	Potential Future Vulnerability	YES
Trawl	*Diomedea dabbenena*	1.00	1.00	0.04	0.68	Potential Future Vulnerability	YES
Trawl	*Pseudobulweria aterrima*	0.70	0.97	0.36	0.68	Potential Future Vulnerability	YES
Trawl	*Alle alle*	0.49	0.72	0.82	0.68	Potential Persisters	YES
Trawl	*Ardenna pacifica*	0.84	0.75	0.42	0.67	Potential Future Vulnerability	YES
Trawl	*Diomedea amsterdamensis*	1.00	0.98	0.04	0.67	Potential Future Vulnerability	YES
Trawl	*Diomedea sanfordi*	1.00	0.98	0.04	0.67	Potential Future Vulnerability	YES
Trawl	*Thalassarche chrysostoma*	1.00	0.98	0.04	0.67	Potential Future Vulnerability	YES
Trawl	*Diomedea antipodensis*	1.00	0.98	0.03	0.67	Potential Future Vulnerability	YES
Trawl	*Phalacrocorax capillatus*	0.73	0.37	0.89	0.66	Potential Adapters	NO
Trawl	*Fregata ariel*	0.84	0.72	0.42	0.66	Potential Future Vulnerability	NO
Trawl	*Pterodroma magentae*	0.84	0.97	0.17	0.66	Potential Future Vulnerability	NO
Trawl	*Megadyptes antipodes*	0.79	0.71	0.47	0.66	Potential Future Vulnerability	YES
Trawl	*Diomedea epomophora*	1.00	0.92	0.04	0.65	Potential Future Vulnerability	YES
Trawl	*Gulosus aristotelis*	0.73	0.34	0.89	0.65	Potential Adapters	YES
Trawl	*Phoebastria immutabilis*	0.94	0.84	0.17	0.65	Potential Future Vulnerability	YES
Trawl	*Diomedea exulans*	1.00	0.91	0.04	0.65	Potential Future Vulnerability	YES
Trawl	*Thalassarche eremita*	1.00	0.91	0.04	0.65	Potential Future Vulnerability	YES
Trawl	*Thalassarche salvini*	1.00	0.91	0.04	0.65	Potential Future Vulnerability	YES

Trawl	*Cepphus grylle*	0.63	0.52	0.80	0.65	Potential Adapters	YES
Trawl	*Thalassarche carteri*	0.94	0.97	0.04	0.65	Potential Future Vulnerability	YES
Trawl	*Thalassarche chlororhynchos*	0.94	0.97	0.04	0.65	Potential Future Vulnerability	YES
Trawl	*Thalassarche impavida*	1.00	0.92	0.03	0.65	Potential Future Vulnerability	YES
Trawl	*Phoebetria fusca*	0.94	0.98	0.03	0.65	Potential Future Vulnerability	YES
Trawl	*Hydrobates leucorhous*	0.50	0.85	0.59	0.65	Potential Persisters	NO
Trawl	*Puffinus huttoni*	0.63	0.95	0.36	0.65	Potential Future Vulnerability	YES
Trawl	*Urile pelagicus*	0.73	0.33	0.87	0.64	Potential Adapters	NO
Trawl	*Pterodroma incerta*	0.84	0.91	0.17	0.64	Potential Future Vulnerability	NO
Trawl	*Pterodroma cahow*	0.70	0.91	0.29	0.63	Potential Future Vulnerability	NO
Trawl	*Fregata andrewsi*	0.94	0.93	0.03	0.63	Potential Future Vulnerability	YES
Trawl	*Spheniscus demersus*	0.79	0.63	0.47	0.63	Potential Future Vulnerability	YES
Trawl	*Hydrobates monorhis*	0.50	0.78	0.61	0.63	Potential Persisters	NO
Trawl	*Larus argentatus*	0.55	0.51	0.82	0.63	Potential Adapters	YES
Trawl	*Thalassarche cauta*	1.00	0.84	0.04	0.62	Potential Future Vulnerability	YES
Trawl	*Thalassarche steadi*	1.00	0.84	0.04	0.62	Potential Future Vulnerability	YES
Trawl	*Larus atlanticus*	0.84	0.58	0.45	0.62	Potential Future Vulnerability	YES
Trawl	*Phalacrocorax capensis*	0.73	0.67	0.47	0.62	Potential Future Vulnerability	YES
Trawl	*Phoebastria nigripes*	1.00	0.81	0.04	0.62	Potential Future Vulnerability	YES
Trawl	*Larus michahellis*	0.55	0.46	0.84	0.62	Potential Adapters	NO
Trawl	*Pseudobulweria becki*	0.84	0.97	0.03	0.61	Potential Future Vulnerability	NO
Trawl	*Pterodroma phaeopygia*	0.84	0.97	0.03	0.61	Potential Future Vulnerability	YES
Trawl	*Puffinus auricularis*	0.84	0.97	0.03	0.61	Potential Future Vulnerability	NO
Trawl	*Larus hyperboreus*	0.55	0.46	0.82	0.61	Potential Adapters	NO
Trawl	*Hydrobates pelagicus*	0.50	0.72	0.61	0.61	Potential Persisters	NO
Trawl	*Nannopterum harrisi*	0.79	0.61	0.42	0.61	Potential Future Vulnerability	YES
Trawl	*Leucocarbo onslowi*	0.73	0.59	0.51	0.61	Potential Future Vulnerability	YES
Trawl	*Fregata aquila*	0.94	0.85	0.03	0.61	Potential Future Vulnerability	YES
Trawl	*Larus pacificus*	0.94	0.48	0.40	0.61	Low Vulnerability	NO
Trawl	*Pterodroma madeira*	0.70	0.95	0.17	0.61	Potential Future Vulnerability	NO
Trawl	*Calonectris diomedea*	0.45	0.75	0.61	0.60	Potential Persisters	YES
Trawl	*Pterodroma sandwichensis*	0.84	0.95	0.03	0.60	Potential Future Vulnerability	YES
Trawl	*Phoebetria palpebrata*	0.94	0.85	0.03	0.60	Potential Future Vulnerability	YES
Trawl	*Thalassarche melanophris*	1.00	0.77	0.04	0.60	Potential Future Vulnerability	YES
Trawl	*Larus audouinii*	0.84	0.51	0.45	0.60	Low Vulnerability	YES
Trawl	*Sula leucogaster*	0.73	0.61	0.46	0.60	Potential Future Vulnerability	NO
Trawl	*Onychoprion aleuticus*	0.70	0.66	0.45	0.60	Potential Future Vulnerability	NO
Trawl	*Spheniscus humboldti*	0.79	0.66	0.36	0.60	Potential Future Vulnerability	YES

Trawl	*Phalacrocorax featherstoni*	0.73	0.57	0.51	0.60	Potential Future Vulnerability	YES
Trawl	*Puffinus newelli*	0.84	0.93	0.03	0.60	Potential Future Vulnerability	YES
Trawl	*Morus serrator*	0.73	0.77	0.29	0.60	Potential Future Vulnerability	YES
Trawl	*Thalassarche bulleri*	0.94	0.81	0.04	0.60	Potential Future Vulnerability	YES
Trawl	*Calonectris borealis*	0.45	0.75	0.59	0.60	Potential Persisters	YES
Trawl	*Ardenna grisea*	0.45	0.84	0.50	0.60	Low Vulnerability	YES
Trawl	*Brachyramphus marmoratus*	0.49	0.85	0.45	0.60	Low Vulnerability	YES
Trawl	*Phalacrocorax neglectus*	0.73	0.55	0.51	0.60	Potential Future Vulnerability	YES
Trawl	*Phalacrocorax carbo*	0.73	0.41	0.65	0.60	Potential Adapters	YES
Trawl	*Onychoprion fuscatus*	0.70	0.66	0.42	0.59	Potential Future Vulnerability	NO
Trawl	*Procellaria parkinsoni*	0.84	0.91	0.03	0.59	Potential Future Vulnerability	YES
Trawl	*Pterodroma atrata*	0.84	0.91	0.03	0.59	Potential Future Vulnerability	NO
Trawl	*Pterodroma baraui*	0.84	0.91	0.03	0.59	Potential Future Vulnerability	NO
Trawl	*Rissa brevirostris*	0.63	0.85	0.29	0.59	Potential Future Vulnerability	YES
Trawl	*Bulweria bulwerii*	0.56	0.77	0.44	0.59	Potential Future Vulnerability	YES
Trawl	*Thalasseus sandvicensis*	0.49	0.52	0.76	0.59	Low Vulnerability	NO
Trawl	*Leucocarbo chalconotus*	0.73	0.53	0.51	0.59	Low Vulnerability	YES
Trawl	*Leucocarbo ranfurlyi*	0.73	0.53	0.51	0.59	Low Vulnerability	NO
Trawl	*Fratercula cirrhata*	0.63	0.77	0.36	0.59	Potential Future Vulnerability	YES
Trawl	*Fratercula corniculata*	0.63	0.77	0.36	0.59	Potential Future Vulnerability	YES
Trawl	*Eudyptes pachyrhynchus*	0.79	0.57	0.40	0.59	Potential Future Vulnerability	YES
Trawl	*Pelecanus thagus*	0.79	0.57	0.40	0.59	Potential Future Vulnerability	YES
Trawl	*Pterodroma deserta*	0.70	0.89	0.17	0.59	Potential Future Vulnerability	NO
Trawl	*Larus modestus*	0.84	0.52	0.40	0.59	Low Vulnerability	NO
Trawl	*Ardenna bulleri*	0.84	0.89	0.03	0.59	Potential Future Vulnerability	YES
Trawl	*Synthliboramphus antiquus*	0.49	0.40	0.87	0.59	Low Vulnerability	NO
Trawl	*Leucocarbo carunculatus*	0.73	0.57	0.45	0.58	Potential Future Vulnerability	YES
Trawl	*Uria lomvia*	0.63	0.72	0.40	0.58	Potential Future Vulnerability	YES
Trawl	*Larus fuscus*	0.45	0.51	0.78	0.58	Low Vulnerability	NO
Trawl	*Sternula balaenarum*	0.56	0.71	0.47	0.58	Potential Future Vulnerability	YES
Trawl	*Pelecanoides garnotii*	0.49	0.85	0.40	0.58	Low Vulnerability	YES
Trawl	*Hydrobates homochroa*	0.50	0.95	0.29	0.58	Low Vulnerability	NO
Trawl	*Pterodroma solandri*	0.84	0.85	0.04	0.58	Potential Future Vulnerability	YES
Trawl	*Fregata magnificens*	0.94	0.75	0.04	0.58	Potential Future Vulnerability	NO
Trawl	*Spheniscus magellanicus*	0.79	0.50	0.45	0.58	Low Vulnerability	YES
Trawl	*Eudyptes robustus*	0.79	0.66	0.29	0.58	Potential Future Vulnerability	YES
Trawl	*Thalasseus bergii*	0.63	0.66	0.44	0.58	Potential Future Vulnerability	NO
Trawl	*Pterodroma arminjoniana*	0.84	0.85	0.03	0.57	Potential Future Vulnerability	NO

Trawl	*Pterodroma cervicalis*	0.84	0.85	0.03	0.57	Potential Future Vulnerability	NO
Trawl	*Pterodroma externa*	0.84	0.85	0.03	0.57	Potential Future Vulnerability	YES
Trawl	*Synthliboramphus scrippsi*	0.70	0.66	0.36	0.57	Potential Future Vulnerability	YES
Trawl	*Larus marinus*	0.44	0.46	0.82	0.57	Low Vulnerability	YES
Trawl	*Oceanites oceanicus*	0.56	0.72	0.44	0.57	Potential Future Vulnerability	NO
Trawl	*Puffinus bryani*	0.70	0.97	0.03	0.57	Potential Future Vulnerability	NO
Trawl	*Puffinus bannermani*	0.70	0.97	0.03	0.56	Potential Future Vulnerability	NO
Trawl	*Fregata minor*	0.94	0.72	0.03	0.56	Potential Future Vulnerability	NO
Trawl	*Pseudobulweria rostrata*	0.84	0.81	0.03	0.56	Potential Future Vulnerability	NO
Trawl	*Cerorhinca monocerata*	0.63	0.58	0.47	0.56	Potential Future Vulnerability	YES
Trawl	*Brachyramphus perdix*	0.49	0.72	0.47	0.56	Low Vulnerability	YES
Trawl	*Eudyptes moseleyi*	0.94	0.71	0.03	0.56	Potential Future Vulnerability	YES
Trawl	*Eudyptes chrysocome*	0.73	0.66	0.29	0.56	Potential Future Vulnerability	NO
Trawl	*Larus smithsonianus*	0.55	0.51	0.61	0.56	Potential Adapters	YES
Trawl	*Pseudobulweria macgillivrayi*	0.70	0.93	0.04	0.56	Potential Future Vulnerability	YES
Trawl	*Leucocarbo campbelli*	0.73	0.57	0.36	0.55	Potential Future Vulnerability	NO
Trawl	*Papasula abbotti*	0.73	0.91	0.03	0.55	Potential Future Vulnerability	YES
Trawl	*Eudyptes sclateri*	0.79	0.71	0.17	0.55	Potential Future Vulnerability	YES
Trawl	*Brachyramphus brevirostris*	0.49	0.72	0.45	0.55	Low Vulnerability	YES
Trawl	*Fregetta maoriana*	0.56	0.93	0.17	0.55	Potential Future Vulnerability	NO
Trawl	*Daption capense*	0.84	0.77	0.04	0.55	Potential Future Vulnerability	NO
Trawl	*Fulmarus glacialoides*	0.84	0.77	0.04	0.55	Potential Future Vulnerability	NO
Trawl	*Aptenodytes forsteri*	0.79	0.84	0.03	0.55	Potential Future Vulnerability	NO
Trawl	*Procellaria conspicillata*	0.55	0.92	0.17	0.55	Potential Future Vulnerability	YES
Trawl	*Larosterna inca*	0.70	0.58	0.36	0.55	Potential Future Vulnerability	YES
Trawl	*Pterodroma alba*	0.70	0.91	0.03	0.55	Potential Future Vulnerability	NO
Trawl	*Pterodroma hasitata*	0.70	0.91	0.03	0.55	Potential Future Vulnerability	NO
Trawl	*Urile penicillatus*	0.73	0.46	0.45	0.54	Low Vulnerability	NO
Trawl	*Spheniscus mendiculus*	0.73	0.61	0.29	0.54	Potential Future Vulnerability	YES
Trawl	*Aphrodroma brevirostris*	0.84	0.75	0.03	0.54	Potential Future Vulnerability	NO
Trawl	*Larus glaucoides*	0.45	0.48	0.69	0.54	Low Vulnerability	NO
Trawl	*Sternula nereis*	0.56	0.66	0.40	0.54	Potential Future Vulnerability	NO
Trawl	*Larus canus*	0.45	0.37	0.78	0.54	Low Vulnerability	NO
Trawl	*Phalacrocorax punctatus*	0.73	0.37	0.51	0.54	Low Vulnerability	NO
Trawl	*Leucocarbo atriceps*	0.73	0.46	0.42	0.54	Low Vulnerability	YES
Trawl	*Hydrobates hornbyi*	0.50	0.81	0.29	0.53	Low Vulnerability	NO
Trawl	*Leucocarbo colensoi*	0.73	0.51	0.36	0.53	Low Vulnerability	NO
Trawl	*Pterodroma gouldi*	0.84	0.72	0.04	0.53	Potential Future Vulnerability	NO

Trawl	*Pterodroma lessonii*	0.84	0.72	0.04	0.53	Potential Future Vulnerability	NO
Trawl	*Pelecanoides magellani*	0.49	0.66	0.45	0.53	Low Vulnerability	NO
Trawl	*Pterodroma axillaris*	0.70	0.85	0.04	0.53	Potential Future Vulnerability	NO
Trawl	*Synthliboramphus wumizusume*	0.49	0.66	0.45	0.53	Low Vulnerability	YES
Trawl	*Sternula lorata*	0.56	0.63	0.40	0.53	Potential Future Vulnerability	YES
Trawl	*Phalacrocorax fuscescens*	0.73	0.44	0.42	0.53	Low Vulnerability	NO
Trawl	*Poikilocarbo gaimardi*	0.73	0.43	0.42	0.53	Low Vulnerability	YES
Trawl	*Larus melanocephalus*	0.31	0.46	0.82	0.53	Low Vulnerability	NO
Trawl	*Pterodroma heraldica*	0.84	0.72	0.03	0.53	Potential Future Vulnerability	NO
Trawl	*Pterodroma macroptera*	0.84	0.72	0.03	0.53	Potential Future Vulnerability	NO
Trawl	*Pterodroma neglecta*	0.84	0.72	0.03	0.53	Potential Future Vulnerability	NO
Trawl	*Pterodroma ultima*	0.84	0.72	0.03	0.53	Potential Future Vulnerability	NO
Trawl	*Thalassoica antarctica*	0.84	0.72	0.03	0.53	Potential Future Vulnerability	NO
Trawl	*Eudyptula minor*	0.73	0.40	0.45	0.53	Low Vulnerability	YES
Trawl	*Pterodroma brevipes*	0.70	0.85	0.03	0.53	Potential Future Vulnerability	NO
Trawl	*Pterodroma cookii*	0.70	0.85	0.03	0.53	Potential Future Vulnerability	NO
Trawl	*Pterodroma defilippiana*	0.70	0.85	0.03	0.53	Potential Future Vulnerability	NO
Trawl	*Pterodroma leucoptera*	0.70	0.85	0.03	0.53	Potential Future Vulnerability	YES
Trawl	*Pterodroma longirostris*	0.70	0.85	0.03	0.53	Potential Future Vulnerability	NO
Trawl	*Catharacta chilensis*	0.55	0.61	0.40	0.52	Potential Future Vulnerability	YES
Trawl	*Bulweria fallax*	0.70	0.84	0.03	0.52	Potential Future Vulnerability	NO
Trawl	*Hydrobates monteiroi*	0.50	0.89	0.17	0.52	Low Vulnerability	NO
Trawl	*Thalasseus bernsteini*	0.70	0.69	0.17	0.52	Potential Future Vulnerability	YES
Trawl	*Pterodroma feae*	0.70	0.81	0.04	0.52	Potential Future Vulnerability	NO
Trawl	*Leucocarbo magellanicus*	0.73	0.37	0.45	0.52	Low Vulnerability	YES
Trawl	*Aptenodytes patagonicus*	0.79	0.72	0.04	0.51	Potential Future Vulnerability	NO
Trawl	*Sterna striata*	0.49	0.58	0.47	0.51	Low Vulnerability	NO
Trawl	*Urile urile*	0.73	0.34	0.47	0.51	Low Vulnerability	NO
Trawl	*Pterodroma pycrofti*	0.70	0.80	0.03	0.51	Potential Future Vulnerability	NO
Trawl	*Cepphus carbo*	0.63	0.44	0.45	0.51	Low Vulnerability	YES
Trawl	*Larus glaucescens*	0.55	0.51	0.45	0.51	Low Vulnerability	NO
Trawl	*Hydroprogne caspia*	0.45	0.48	0.59	0.50	Low Vulnerability	NO
Trawl	*Ardenna creatopus*	0.45	0.89	0.17	0.50	Low Vulnerability	YES
Trawl	*Thalasseus maximus*	0.63	0.52	0.36	0.50	Low Vulnerability	NO
Trawl	*Hydrobates furcatus*	0.50	0.72	0.29	0.50	Low Vulnerability	NO
Trawl	*Procellaria aequinoctialis*	0.55	0.91	0.04	0.50	Potential Future Vulnerability	YES
Trawl	*Pagodroma nivea*	0.70	0.77	0.03	0.50	Potential Future Vulnerability	NO
Trawl	*Puffinus bailloni*	0.70	0.77	0.03	0.50	Potential Future Vulnerability	NO

Trawl	*Sula variegata*	0.73	0.48	0.29	0.50	Low Vulnerability	NO
Trawl	*Nesofregetta fuliginosa*	0.56	0.91	0.03	0.50	Potential Future Vulnerability	NO
Trawl	*Cepphus columba*	0.63	0.44	0.42	0.50	Low Vulnerability	YES
Trawl	*Synthliboramphus hypoleucus*	0.49	0.71	0.29	0.50	Low Vulnerability	YES
Trawl	*Aethia pygmaea*	0.49	0.54	0.45	0.49	Low Vulnerability	NO
Trawl	*Puffinus persicus*	0.70	0.75	0.03	0.49	Potential Future Vulnerability	NO
Trawl	*Eudyptes chrysolophus*	0.79	0.66	0.04	0.49	Potential Future Vulnerability	YES
Trawl	*Sula sula*	0.73	0.72	0.03	0.49	Potential Future Vulnerability	NO
Trawl	*Larus ridibundus*	0.31	0.37	0.78	0.49	Low Vulnerability	NO
Trawl	*Pelecanus occidentalis*	0.79	0.51	0.17	0.49	Low Vulnerability	YES
Trawl	*Aethia cristatella*	0.49	0.58	0.40	0.49	Low Vulnerability	NO
Trawl	*Sterna dougallii*	0.49	0.52	0.46	0.49	Low Vulnerability	YES
Trawl	*Larus schistisagus*	0.55	0.46	0.45	0.49	Low Vulnerability	NO
Trawl	*Pachyptila belcheri*	0.70	0.72	0.04	0.49	Potential Future Vulnerability	NO
Trawl	*Pterodroma hypoleuca*	0.70	0.72	0.04	0.49	Potential Future Vulnerability	NO
Trawl	*Pterodroma mollis*	0.70	0.72	0.04	0.49	Potential Future Vulnerability	NO
Trawl	*Larus genei*	0.31	0.46	0.69	0.49	Low Vulnerability	NO
Trawl	*Anous stolidus*	0.70	0.72	0.03	0.48	Potential Future Vulnerability	NO
Trawl	*Gygis alba*	0.70	0.72	0.03	0.48	Potential Future Vulnerability	NO
Trawl	*Pterodroma nigripennis*	0.70	0.72	0.03	0.48	Potential Future Vulnerability	NO
Trawl	*Sterna hirundo*	0.49	0.48	0.48	0.48	Low Vulnerability	NO
Trawl	*Pelecanus conspicillatus*	0.79	0.61	0.04	0.48	Potential Future Vulnerability	NO
Trawl	*Synthliboramphus craveri*	0.49	0.66	0.29	0.48	Low Vulnerability	YES
Trawl	*Pelecanoides urinatrix*	0.49	0.66	0.29	0.48	Low Vulnerability	NO
Trawl	*Larus fuliginosus*	0.45	0.53	0.45	0.48	Low Vulnerability	YES
Trawl	*Oceanites pincoyae*	0.50	0.43	0.51	0.48	Low Vulnerability	NO
Trawl	*Calonectris edwardsii*	0.45	0.81	0.17	0.48	Low Vulnerability	NO
Trawl	*Procellaria cinerea*	0.55	0.84	0.04	0.48	Potential Future Vulnerability	YES
Trawl	*Puffinus lherminieri*	0.49	0.77	0.17	0.48	Low Vulnerability	NO
Trawl	*Phalacrocorax nigrogularis*	0.73	0.53	0.17	0.48	Low Vulnerability	YES
Trawl	*Sterna sumatrana*	0.49	0.52	0.42	0.48	Low Vulnerability	NO
Trawl	*Eudyptes schlegeli*	0.79	0.64	0.00	0.47	Potential Future Vulnerability	YES
Trawl	*Gygis microrhyncha*	0.70	0.72	0.00	0.47	Potential Future Vulnerability	NO
Trawl	*Puffinus elegans*	0.49	0.75	0.17	0.47	Low Vulnerability	NO
Trawl	*Puffinus gavia*	0.49	0.75	0.17	0.47	Low Vulnerability	YES
Trawl	*Puffinus nativitatis*	0.63	0.75	0.03	0.47	Potential Future Vulnerability	NO
Trawl	*Macronectes halli*	0.61	0.75	0.04	0.47	Potential Future Vulnerability	YES
Trawl	*Pelecanus erythrorhynchos*	0.79	0.58	0.04	0.47	Potential Future Vulnerability	NO

Trawl	*Halobaena caerulea*	0.70	0.66	0.04	0.47	Potential Future Vulnerability	NO
Trawl	*Onychoprion anaethetus*	0.70	0.66	0.04	0.47	Potential Future Vulnerability	NO
Trawl	*Pachyptila desolata*	0.70	0.66	0.04	0.47	Potential Future Vulnerability	NO
Trawl	*Pachyptila salvini*	0.70	0.66	0.04	0.47	Potential Future Vulnerability	NO
Trawl	*Pachyptila vittata*	0.70	0.66	0.04	0.47	Potential Future Vulnerability	NO
Trawl	*Sterna hirundinacea*	0.49	0.48	0.42	0.46	Low Vulnerability	NO
Trawl	*Pelecanus onocrotalus*	0.79	0.58	0.03	0.46	Potential Future Vulnerability	NO
Trawl	*Pelecanus rufescens*	0.79	0.58	0.03	0.46	Potential Future Vulnerability	NO
Trawl	*Pelecanus philippensis*	0.79	0.57	0.03	0.46	Potential Future Vulnerability	YES
Trawl	*Anous minutus*	0.70	0.66	0.03	0.46	Potential Future Vulnerability	NO
Trawl	*Anous tenuirostris*	0.70	0.66	0.03	0.46	Potential Future Vulnerability	NO
Trawl	*Onychoprion lunatus*	0.70	0.66	0.03	0.46	Potential Future Vulnerability	NO
Trawl	*Ptychoramphus aleuticus*	0.49	0.60	0.29	0.46	Low Vulnerability	YES
Trawl	*Larus bulleri*	0.20	0.71	0.47	0.46	Low Vulnerability	NO
Trawl	*Puffinus heinrothi*	0.49	0.89	0.00	0.46	Low Vulnerability	NO
Trawl	*Hydrobates matsudairae*	0.50	0.85	0.03	0.46	Low Vulnerability	NO
Trawl	*Ardenna gravis*	0.45	0.75	0.17	0.46	Low Vulnerability	YES
Trawl	*Creagrus furcatus*	0.45	0.75	0.17	0.46	Low Vulnerability	NO
Trawl	*Sterna virgata*	0.49	0.72	0.17	0.46	Low Vulnerability	NO
Trawl	*Thalasseus elegans*	0.49	0.72	0.17	0.46	Low Vulnerability	YES
Trawl	*Stercorarius pomarinus*	0.34	0.58	0.46	0.46	Low Vulnerability	NO
Trawl	*Phaethon rubricauda*	0.63	0.72	0.03	0.46	Potential Future Vulnerability	NO
Trawl	*Sterna vittata*	0.49	0.52	0.36	0.46	Low Vulnerability	NO
Trawl	*Sula dactylatra*	0.73	0.61	0.03	0.46	Potential Future Vulnerability	NO
Trawl	*Rhodostethia rosea*	0.70	0.37	0.29	0.46	Low Vulnerability	NO
Trawl	*Larus hemprichii*	0.84	0.48	0.04	0.45	Low Vulnerability	NO
Trawl	*Microcarbo coronatus*	0.45	0.40	0.51	0.45	Low Vulnerability	NO
Trawl	*Hydrobates markhami*	0.50	0.81	0.04	0.45	Low Vulnerability	NO
Trawl	*Hydrocoloeus minutus*	0.31	0.46	0.59	0.45	Low Vulnerability	NO
Trawl	*Larus leucophthalmus*	0.84	0.48	0.03	0.45	Low Vulnerability	YES
Trawl	*Pelecanus crispus*	0.79	0.52	0.04	0.45	Low Vulnerability	YES
Trawl	*Larus thayeri*	0.84	0.46	0.04	0.45	Low Vulnerability	NO
Trawl	*Larus hartlaubii*	0.31	0.52	0.51	0.45	Low Vulnerability	NO
Trawl	*Catharacta maccormicki*	0.55	0.61	0.17	0.44	Potential Future Vulnerability	NO
Trawl	*Larus dominicanus*	0.45	0.48	0.40	0.44	Low Vulnerability	NO
Trawl	*Pygoscelis adeliae*	0.79	0.52	0.03	0.44	Low Vulnerability	YES
Trawl	*Phaethon aethereus*	0.63	0.66	0.04	0.44	Potential Future Vulnerability	NO
Trawl	*Rynchops albicollis*	0.70	0.59	0.03	0.44	Potential Future Vulnerability	NO

Trawl	*Phaethon lepturus*	0.63	0.66	0.03	0.44	Potential Future Vulnerability	NO
Trawl	*Fregetta grallaria*	0.56	0.72	0.04	0.44	Potential Future Vulnerability	NO
Trawl	*Garrodia nereis*	0.56	0.72	0.04	0.44	Potential Future Vulnerability	NO
Trawl	*Pelagodroma marina*	0.56	0.72	0.04	0.44	Potential Future Vulnerability	NO
Trawl	*Macronectes giganteus*	0.50	0.77	0.04	0.44	Low Vulnerability	YES
Trawl	*Ardenna carneipes*	0.45	0.81	0.04	0.44	Low Vulnerability	YES
Trawl	*Puffinus opisthomelas*	0.45	0.81	0.04	0.44	Low Vulnerability	YES
Trawl	*Sterna paradisaea*	0.70	0.58	0.03	0.44	Potential Future Vulnerability	YES
Trawl	*Fregetta tropica*	0.56	0.72	0.03	0.43	Potential Future Vulnerability	NO
Trawl	*Larus livens*	0.55	0.46	0.29	0.43	Low Vulnerability	NO
Trawl	*Hydrobates castro*	0.50	0.75	0.04	0.43	Low Vulnerability	NO
Trawl	*Aethia pusilla*	0.35	0.54	0.40	0.43	Low Vulnerability	NO
Trawl	*Puffinus assimilis*	0.49	0.75	0.04	0.43	Low Vulnerability	NO
Trawl	*Larus occidentalis*	0.34	0.51	0.42	0.43	Low Vulnerability	NO
Trawl	*Sternula albifrons*	0.17	0.48	0.63	0.43	Low Vulnerability	NO
Trawl	*Puffinus subalaris*	0.49	0.75	0.03	0.42	Low Vulnerability	NO
Trawl	*Sterna trudeaui*	0.49	0.42	0.36	0.42	Low Vulnerability	NO
Trawl	*Larus belcheri*	0.45	0.46	0.36	0.42	Low Vulnerability	NO
Trawl	*Chlidonias albostriatus*	0.17	0.65	0.45	0.42	Low Vulnerability	NO
Trawl	*Rynchops flavirostris*	0.70	0.54	0.03	0.42	Low Vulnerability	YES
Trawl	*Pachyptila crassirostris*	0.31	0.66	0.29	0.42	Low Vulnerability	NO
Trawl	*Hydrobates melania*	0.50	0.72	0.04	0.42	Low Vulnerability	NO
Trawl	*Hydrobates microsoma*	0.50	0.72	0.04	0.42	Low Vulnerability	NO
Trawl	*Hydrobates tethys*	0.50	0.72	0.04	0.42	Low Vulnerability	NO
Trawl	*Hydrobates tristrami*	0.50	0.72	0.04	0.42	Low Vulnerability	NO
Trawl	*Pterodroma inexpectata*	0.45	0.78	0.03	0.42	Low Vulnerability	NO
Trawl	*Pygoscelis antarcticus*	0.79	0.44	0.03	0.42	Low Vulnerability	YES
Trawl	*Ardenna tenuirostris*	0.45	0.75	0.04	0.42	Low Vulnerability	YES
Trawl	*Nannopterum auritus*	0.73	0.34	0.17	0.41	Low Vulnerability	NO
Trawl	*Phalacrocorax varius*	0.73	0.34	0.17	0.41	Low Vulnerability	NO
Trawl	*Pygoscelis papua*	0.79	0.40	0.04	0.41	Low Vulnerability	YES
Trawl	*Stercorarius parasiticus*	0.34	0.58	0.29	0.40	Low Vulnerability	NO
Trawl	*Sula granti*	0.73	0.44	0.04	0.40	Low Vulnerability	NO
Trawl	*Sula nebouxii*	0.73	0.44	0.04	0.40	Low Vulnerability	NO
Trawl	*Aethia psittacula*	0.49	0.54	0.17	0.40	Low Vulnerability	NO
Trawl	*Gelochelidon nilotica*	0.31	0.42	0.46	0.40	Low Vulnerability	NO
Trawl	*Pelecanoides georgicus*	0.49	0.66	0.04	0.40	Low Vulnerability	NO
Trawl	*Thalasseus bengalensis*	0.49	0.66	0.04	0.40	Low Vulnerability	NO

Trawl	*Anous albivittus*	0.56	0.58	0.03	0.39	Potential Future Vulnerability	NO
Trawl	*Anous ceruleus*	0.56	0.58	0.03	0.39	Potential Future Vulnerability	NO
Trawl	*Larus heermanni*	0.45	0.54	0.17	0.39	Low Vulnerability	YES
Trawl	*Rynchops niger*	0.70	0.41	0.04	0.38	Low Vulnerability	NO
Trawl	*Pachyptila turtur*	0.31	0.66	0.17	0.38	Low Vulnerability	NO
Trawl	*Larus armenicus*	0.45	0.52	0.17	0.38	Low Vulnerability	NO
Trawl	*Phalacrocorax sulcirostris*	0.63	0.33	0.17	0.38	Low Vulnerability	NO
Trawl	*Oceanites gracilis*	0.50	0.43	0.17	0.37	Low Vulnerability	NO
Trawl	*Catharacta antarctica*	0.44	0.61	0.04	0.36	Low Vulnerability	NO
Trawl	*Nannopterum brasilianus*	0.73	0.34	0.03	0.36	Low Vulnerability	NO
Trawl	*Pagophila eburnea*	0.34	0.58	0.17	0.36	Low Vulnerability	NO
Trawl	*Larus maculipennis*	0.34	0.46	0.29	0.36	Low Vulnerability	NO
Trawl	*Larus novaehollandiae*	0.31	0.48	0.29	0.36	Low Vulnerability	NO
Trawl	*Sternula saundersi*	0.56	0.48	0.04	0.36	Low Vulnerability	NO
Trawl	*Larus ichthyaetus*	0.55	0.48	0.03	0.35	Low Vulnerability	NO
Trawl	*Larus cachinnans*	0.55	0.46	0.04	0.35	Low Vulnerability	NO
Trawl	*Sterna repressa*	0.35	0.52	0.17	0.34	Low Vulnerability	NO
Trawl	*Sterna aurantia*	0.49	0.52	0.03	0.34	Low Vulnerability	NO
Trawl	*Larus relictus*	0.45	0.53	0.03	0.34	Low Vulnerability	NO
Trawl	*Sterna acuticauda*	0.31	0.65	0.03	0.33	Low Vulnerability	YES
Trawl	*Chlidonias hybrida*	0.17	0.37	0.44	0.33	Low Vulnerability	NO
Trawl	*Sterna forsteri*	0.49	0.46	0.04	0.33	Low Vulnerability	NO
Trawl	*Phalacrocorax fuscicollis*	0.63	0.33	0.03	0.33	Low Vulnerability	NO
Trawl	*Chlidonias niger*	0.56	0.37	0.04	0.32	Low Vulnerability	NO
Trawl	*Larus brunnicephalus*	0.45	0.48	0.04	0.32	Low Vulnerability	NO
Trawl	*Larus cirrocephalus*	0.45	0.48	0.04	0.32	Low Vulnerability	NO
Trawl	*Larus serranus*	0.45	0.48	0.04	0.32	Low Vulnerability	NO
Trawl	*Chlidonias leucopterus*	0.17	0.37	0.42	0.32	Low Vulnerability	NO
Trawl	*Microcarbo melanoleucos*	0.45	0.33	0.17	0.32	Low Vulnerability	NO
Trawl	*Larus atricilla*	0.31	0.46	0.17	0.31	Low Vulnerability	NO
Trawl	*Microcarbo niger*	0.45	0.37	0.03	0.28	Low Vulnerability	NO
Trawl	*Xema sabini*	0.20	0.36	0.29	0.28	Low Vulnerability	NO
Trawl	*Larus californicus*	0.34	0.46	0.04	0.28	Low Vulnerability	NO
Trawl	*Larus delawarensis*	0.34	0.46	0.04	0.28	Low Vulnerability	NO
Trawl	*Microcarbo africanus*	0.45	0.33	0.04	0.27	Low Vulnerability	YES
Trawl	*Phaetusa simplex*	0.31	0.48	0.03	0.27	Low Vulnerability	NO
Trawl	*Sternula antillarum*	0.17	0.48	0.17	0.27	Low Vulnerability	NO
Trawl	*Larus philadelphia*	0.31	0.46	0.04	0.27	Low Vulnerability	NO

Trawl	*Larus pipixcan*	0.31	0.46	0.04	0.27	Low Vulnerability	NO
Trawl	*Stercorarius longicaudus*	0.20	0.52	0.03	0.25	Low Vulnerability	NO
Trawl	*Sternula superciliaris*	0.17	0.48	0.03	0.22	Low Vulnerability	NO

Table B.3 Purse seine vulnerability scores for all seabirds. IUCN indicates whether the species is classified as threatened from bycatch by the International Union for Conservation of Nature.

Gear	Species	Sensitivity	Adaptive	Exposure	Vulnerability	Vulnerability Class	IUCN
Purse Seine	*Phoebastria irrorata*	1.00	1.00	0.55	0.85	Potential Future Vulnerability	YES
Purse Seine	*Phoebastria albatrus*	1.00	0.91	0.57	0.83	High Vulnerability	YES
Purse Seine	*Phoebastria nigripes*	1.00	0.81	0.57	0.79	High Vulnerability	YES
Purse Seine	*Phoebastria immutabilis*	0.94	0.84	0.55	0.78	High Vulnerability	YES
Purse Seine	*Larus crassirostris*	0.84	0.52	0.98	0.78	Potential Adapters	NO
Purse Seine	*Calonectris leucomelas*	0.84	0.81	0.59	0.75	High Vulnerability	YES
Purse Seine	*Diomedea dabbenena*	1.00	1.00	0.17	0.72	Potential Future Vulnerability	YES
Purse Seine	*Cerorhinca monocerata*	0.63	0.58	0.94	0.72	High Vulnerability	YES
Purse Seine	*Ardenna pacifica*	0.84	0.75	0.55	0.72	High Vulnerability	YES
Purse Seine	*Diomedea amsterdamensis*	1.00	0.98	0.17	0.72	Potential Future Vulnerability	YES
Purse Seine	*Diomedea antipodensis*	1.00	0.98	0.17	0.72	Potential Future Vulnerability	YES
Purse Seine	*Diomedea sanfordi*	1.00	0.98	0.17	0.72	Potential Future Vulnerability	YES
Purse Seine	*Thalassarche chrysostoma*	1.00	0.98	0.17	0.72	Potential Future Vulnerability	YES
Purse Seine	*Puffinus mauretanicus*	0.63	0.97	0.52	0.71	Potential Future Vulnerability	YES
Purse Seine	*Diomedea epomophora*	1.00	0.92	0.17	0.70	Potential Future Vulnerability	YES
Purse Seine	*Thalassarche impavida*	1.00	0.92	0.17	0.70	Potential Future Vulnerability	YES
Purse Seine	*Thalassarche eremita*	1.00	0.91	0.18	0.70	Potential Future Vulnerability	YES
Purse Seine	*Thalassarche salvini*	1.00	0.91	0.18	0.70	Potential Future Vulnerability	YES
Purse Seine	*Phoebetria fusca*	0.94	0.98	0.17	0.70	Potential Future Vulnerability	YES
Purse Seine	*Procellaria westlandica*	0.94	0.98	0.17	0.70	Potential Future Vulnerability	YES
Purse Seine	*Diomedea exulans*	1.00	0.91	0.17	0.69	Potential Future Vulnerability	YES
Purse Seine	*Thalassarche carteri*	0.94	0.97	0.17	0.69	Potential Future Vulnerability	YES
Purse Seine	*Thalassarche chlororhynchos*	0.94	0.97	0.17	0.69	Potential Future Vulnerability	YES
Purse Seine	*Phalacrocorax capillatus*	0.73	0.37	0.97	0.69	Potential Adapters	NO
Purse Seine	*Puffinus yelkouan*	0.63	0.89	0.52	0.68	Potential Future Vulnerability	YES
Purse Seine	*Fregata andrewsi*	0.94	0.93	0.17	0.68	Potential Future Vulnerability	YES
Purse Seine	*Spheniscus humboldti*	0.79	0.66	0.59	0.68	High Vulnerability	YES
Purse Seine	*Urile pelagicus*	0.73	0.33	0.96	0.67	Potential Adapters	NO
Purse Seine	*Thalassarche cauta*	1.00	0.84	0.17	0.67	Potential Future Vulnerability	YES
Purse Seine	*Thalassarche steadi*	1.00	0.84	0.17	0.67	Potential Future Vulnerability	YES
Purse Seine	*Pterodroma phaeopygia*	0.84	0.97	0.17	0.66	Potential Future Vulnerability	YES
Purse Seine	*Hydrobates homochroa*	0.50	0.95	0.52	0.66	Low Vulnerability	NO
Purse Seine	*Phoebetria palpebrata*	0.94	0.85	0.17	0.65	Potential Future Vulnerability	YES
Purse Seine	*Pelecanus thagus*	0.79	0.57	0.59	0.65	High Vulnerability	YES

Purse Seine	*Thalassarche melanophris*	1.00	0.77	0.18	0.65	Potential Future Vulnerability	YES
Purse Seine	*Larus modestus*	0.84	0.52	0.59	0.65	Potential Adapters	NO
Purse Seine	*Thalasseus bernsteini*	0.70	0.69	0.55	0.65	Potential Future Vulnerability	YES
Purse Seine	*Spheniscus demersus*	0.79	0.63	0.52	0.65	Potential Future Vulnerability	YES
Purse Seine	*Thalassarche bulleri*	0.94	0.81	0.18	0.64	Potential Future Vulnerability	YES
Purse Seine	*Pelecanoides garnotii*	0.49	0.85	0.59	0.64	Potential Persisters	YES
Purse Seine	*Sula leucogaster*	0.73	0.61	0.59	0.64	High Vulnerability	NO
Purse Seine	*Procellaria parkinsoni*	0.84	0.91	0.17	0.64	Potential Future Vulnerability	YES
Purse Seine	*Pterodroma baraui*	0.84	0.91	0.17	0.64	Potential Future Vulnerability	NO
Purse Seine	*Pterodroma incerta*	0.84	0.91	0.17	0.64	Potential Future Vulnerability	NO
Purse Seine	*Phalacrocorax capensis*	0.73	0.67	0.52	0.64	Potential Future Vulnerability	YES
Purse Seine	*Ardenna bulleri*	0.84	0.89	0.18	0.64	Potential Future Vulnerability	YES
Purse Seine	*Hydrobates hornbyi*	0.50	0.81	0.58	0.63	Potential Persisters	NO
Purse Seine	*Bulweria bulwerii*	0.56	0.77	0.55	0.63	High Vulnerability	YES
Purse Seine	*Larus audouinii*	0.84	0.51	0.52	0.63	Low Vulnerability	YES
Purse Seine	*Synthliboramphus scrippsi*	0.70	0.66	0.52	0.63	Potential Future Vulnerability	YES
Purse Seine	*Ardenna creatopus*	0.45	0.89	0.53	0.62	Low Vulnerability	YES
Purse Seine	*Larosterna inca*	0.70	0.58	0.59	0.62	High Vulnerability	YES
Purse Seine	*Pterodroma arminjoniana*	0.84	0.85	0.17	0.62	Potential Future Vulnerability	NO
Purse Seine	*Pterodroma cervicalis*	0.84	0.85	0.17	0.62	Potential Future Vulnerability	NO
Purse Seine	*Pterodroma externa*	0.84	0.85	0.17	0.62	Potential Future Vulnerability	YES
Purse Seine	*Pterodroma solandri*	0.84	0.85	0.17	0.62	Potential Future Vulnerability	YES
Purse Seine	*Morus capensis*	0.73	0.97	0.17	0.62	Potential Future Vulnerability	YES
Purse Seine	*Fregata magnificens*	0.94	0.75	0.17	0.62	Potential Future Vulnerability	NO
Purse Seine	*Hydrobates monorhis*	0.50	0.78	0.59	0.62	Potential Persisters	NO
Purse Seine	*Phalacrocorax neglectus*	0.73	0.55	0.56	0.62	High Vulnerability	YES
Purse Seine	*Synthliboramphus antiquus*	0.49	0.40	0.95	0.62	Low Vulnerability	NO
Purse Seine	*Thalasseus bergii*	0.63	0.66	0.55	0.61	High Vulnerability	NO
Purse Seine	*Fregata minor*	0.94	0.72	0.17	0.61	Potential Future Vulnerability	NO
Purse Seine	*Eudyptes moseleyi*	0.94	0.71	0.17	0.61	Potential Future Vulnerability	YES
Purse Seine	*Pterodroma madeira*	0.70	0.95	0.17	0.61	Potential Future Vulnerability	NO
Purse Seine	*Pseudobulweria becki*	0.84	0.97	0.00	0.60	Potential Future Vulnerability	NO
Purse Seine	*Pterodroma magentae*	0.84	0.97	0.00	0.60	Potential Future Vulnerability	NO
Purse Seine	*Puffinus auricularis*	0.84	0.97	0.00	0.60	Potential Future Vulnerability	NO
Purse Seine	*Spheniscus magellanicus*	0.79	0.50	0.52	0.60	Low Vulnerability	YES
Purse Seine	*Fulmarus glacialis*	0.84	0.78	0.17	0.60	Potential Future Vulnerability	YES
Purse Seine	*Daption capense*	0.84	0.77	0.18	0.60	Potential Future Vulnerability	NO
Purse Seine	*Fregata aquila*	0.94	0.85	0.00	0.60	Potential Future Vulnerability	YES

Purse Seine	*Sula variegata*	0.73	0.48	0.59	0.60	Potential Adapters	NO
Purse Seine	*Sternula balaenarum*	0.56	0.71	0.52	0.60	Potential Future Vulnerability	YES
Purse Seine	*Fulmarus glacialoides*	0.84	0.77	0.17	0.60	Potential Future Vulnerability	NO
Purse Seine	*Pterodroma sandwichensis*	0.84	0.95	0.00	0.60	Potential Future Vulnerability	YES
Purse Seine	*Pterodroma cahow*	0.70	0.91	0.17	0.59	Potential Future Vulnerability	NO
Purse Seine	*Sternula lorata*	0.56	0.63	0.59	0.59	High Vulnerability	YES
Purse Seine	*Puffinus newelli*	0.84	0.93	0.00	0.59	Potential Future Vulnerability	YES
Purse Seine	*Aphrodroma brevirostris*	0.84	0.75	0.17	0.59	Potential Future Vulnerability	NO
Purse Seine	*Pterodroma deserta*	0.70	0.89	0.17	0.59	Potential Future Vulnerability	NO
Purse Seine	*Thalasseus elegans*	0.49	0.72	0.55	0.59	Potential Persisters	YES
Purse Seine	*Pterodroma atrata*	0.84	0.91	0.00	0.58	Potential Future Vulnerability	NO
Purse Seine	*Poikilocarbo gaimardi*	0.73	0.43	0.59	0.58	Potential Adapters	YES
Purse Seine	*Puffinus huttoni*	0.63	0.95	0.17	0.58	Potential Future Vulnerability	YES
Purse Seine	*Catharacta chilensis*	0.55	0.61	0.57	0.58	High Vulnerability	YES
Purse Seine	*Fregata ariel*	0.84	0.72	0.18	0.58	Potential Future Vulnerability	NO
Purse Seine	*Pterodroma axillaris*	0.70	0.85	0.18	0.58	Potential Future Vulnerability	NO
Purse Seine	*Pterodroma cookii*	0.70	0.85	0.18	0.58	Potential Future Vulnerability	NO
Purse Seine	*Pterodroma heraldica*	0.84	0.72	0.17	0.58	Potential Future Vulnerability	NO
Purse Seine	*Pterodroma lessonii*	0.84	0.72	0.17	0.58	Potential Future Vulnerability	NO
Purse Seine	*Pterodroma macroptera*	0.84	0.72	0.17	0.58	Potential Future Vulnerability	NO
Purse Seine	*Pterodroma neglecta*	0.84	0.72	0.17	0.58	Potential Future Vulnerability	NO
Purse Seine	*Pterodroma ultima*	0.84	0.72	0.17	0.58	Potential Future Vulnerability	NO
Purse Seine	*Thalassoica antarctica*	0.84	0.72	0.17	0.58	Potential Future Vulnerability	NO
Purse Seine	*Creagrus furcatus*	0.45	0.75	0.52	0.58	Low Vulnerability	NO
Purse Seine	*Pterodroma defilippiana*	0.70	0.85	0.17	0.58	Potential Future Vulnerability	NO
Purse Seine	*Pterodroma leucoptera*	0.70	0.85	0.17	0.58	Potential Future Vulnerability	YES
Purse Seine	*Pterodroma longirostris*	0.70	0.85	0.17	0.58	Potential Future Vulnerability	NO
Purse Seine	*Catharacta skua*	0.94	0.61	0.17	0.58	Potential Future Vulnerability	YES
Purse Seine	*Fratercula arctica*	0.63	0.91	0.17	0.57	Potential Future Vulnerability	YES
Purse Seine	*Bulweria fallax*	0.70	0.84	0.17	0.57	Potential Future Vulnerability	NO
Purse Seine	*Urile penicillatus*	0.73	0.46	0.52	0.57	Low Vulnerability	NO
Purse Seine	*Sula nebouxii*	0.73	0.44	0.53	0.57	Low Vulnerability	NO
Purse Seine	*Phalacrocorax carbo*	0.73	0.41	0.55	0.56	Potential Adapters	YES
Purse Seine	*Synthliboramphus wumizusume*	0.49	0.66	0.55	0.56	Low Vulnerability	YES
Purse Seine	*Pterodroma feae*	0.70	0.81	0.17	0.56	Potential Future Vulnerability	NO
Purse Seine	*Aptenodytes patagonicus*	0.79	0.72	0.17	0.56	Potential Future Vulnerability	NO
Purse Seine	*Morus bassanus*	0.73	0.77	0.17	0.56	Potential Future Vulnerability	YES
Purse Seine	*Morus serrator*	0.73	0.77	0.17	0.56	Potential Future Vulnerability	YES

Purse Seine	*Pseudobulweria aterrima*	0.70	0.97	0.00	0.56	Potential Future Vulnerability	YES
Purse Seine	*Puffinus bryani*	0.70	0.97	0.00	0.56	Potential Future Vulnerability	NO
Purse Seine	*Puffinus bannermani*	0.70	0.97	0.00	0.56	Potential Future Vulnerability	NO
Purse Seine	*Rissa brevirostris*	0.63	0.85	0.17	0.55	Potential Future Vulnerability	YES
Purse Seine	*Pseudobulweria rostrata*	0.84	0.81	0.00	0.55	Potential Future Vulnerability	NO
Purse Seine	*Larus smithsonianus*	0.55	0.51	0.59	0.55	Potential Adapters	YES
Purse Seine	*Puffinus bailloni*	0.70	0.77	0.17	0.55	Potential Future Vulnerability	NO
Purse Seine	*Procellaria conspicillata*	0.55	0.92	0.17	0.55	Potential Future Vulnerability	YES
Purse Seine	*Procellaria aequinoctialis*	0.55	0.91	0.18	0.55	Potential Future Vulnerability	YES
Purse Seine	*Papasula abbotti*	0.73	0.91	0.00	0.55	Potential Future Vulnerability	YES
Purse Seine	*Pseudobulweria macgillivrayi*	0.70	0.93	0.00	0.54	Potential Future Vulnerability	YES
Purse Seine	*Puffinus persicus*	0.70	0.75	0.17	0.54	Potential Future Vulnerability	NO
Purse Seine	*Aptenodytes forsteri*	0.79	0.84	0.00	0.54	Potential Future Vulnerability	NO
Purse Seine	*Sula sula*	0.73	0.72	0.17	0.54	Potential Future Vulnerability	NO
Purse Seine	*Pterodroma alba*	0.70	0.91	0.00	0.54	Potential Future Vulnerability	NO
Purse Seine	*Pterodroma hasitata*	0.70	0.91	0.00	0.54	Potential Future Vulnerability	NO
Purse Seine	*Pachyptila belcheri*	0.70	0.72	0.18	0.53	Potential Future Vulnerability	NO
Purse Seine	*Larus atlanticus*	0.84	0.58	0.17	0.53	Potential Future Vulnerability	YES
Purse Seine	*Anous stolidus*	0.70	0.72	0.17	0.53	Potential Future Vulnerability	NO
Purse Seine	*Pterodroma hypoleuca*	0.70	0.72	0.17	0.53	Potential Future Vulnerability	NO
Purse Seine	*Pterodroma mollis*	0.70	0.72	0.17	0.53	Potential Future Vulnerability	NO
Purse Seine	*Pterodroma nigripennis*	0.70	0.72	0.17	0.53	Potential Future Vulnerability	NO
Purse Seine	*Larus pacificus*	0.94	0.48	0.17	0.53	Low Vulnerability	NO
Purse Seine	*Alca torda*	0.63	0.78	0.17	0.53	Potential Future Vulnerability	YES
Purse Seine	*Sterna dougallii*	0.49	0.52	0.57	0.53	Low Vulnerability	YES
Purse Seine	*Fratercula cirrhata*	0.63	0.77	0.17	0.53	Potential Future Vulnerability	YES
Purse Seine	*Fratercula corniculata*	0.63	0.77	0.17	0.53	Potential Future Vulnerability	YES
Purse Seine	*Procellaria cinerea*	0.55	0.84	0.18	0.53	Potential Future Vulnerability	YES
Purse Seine	*Pelecanus conspicillatus*	0.79	0.61	0.17	0.52	Potential Future Vulnerability	NO
Purse Seine	*Larus schistisagus*	0.55	0.46	0.56	0.52	Potential Adapters	NO
Purse Seine	*Pterodroma gouldi*	0.84	0.72	0.00	0.52	Potential Future Vulnerability	NO
Purse Seine	*Puffinus puffinus*	0.63	0.75	0.17	0.52	Potential Future Vulnerability	NO
Purse Seine	*Eudyptes chrysocome*	0.73	0.66	0.17	0.52	Potential Future Vulnerability	NO
Purse Seine	*Pterodroma brevipes*	0.70	0.85	0.00	0.52	Potential Future Vulnerability	NO
Purse Seine	*Larus fuscus*	0.45	0.51	0.58	0.52	Low Vulnerability	NO
Purse Seine	*Onychoprion fuscatus*	0.70	0.66	0.18	0.51	Potential Future Vulnerability	NO
Purse Seine	*Macronectes halli*	0.61	0.75	0.17	0.51	Potential Future Vulnerability	YES
Purse Seine	*Pelecanus erythrorhynchos*	0.79	0.58	0.17	0.51	Potential Future Vulnerability	NO

Purse Seine	*Pelecanus onocrotalus*	0.79	0.58	0.17	0.51	Potential Future Vulnerability	NO
Purse Seine	*Pelecanus rufescens*	0.79	0.58	0.17	0.51	Potential Future Vulnerability	NO
Purse Seine	*Pelecanus philippensis*	0.79	0.57	0.17	0.51	Potential Future Vulnerability	YES
Purse Seine	*Anous minutus*	0.70	0.66	0.17	0.51	Potential Future Vulnerability	NO
Purse Seine	*Anous tenuirostris*	0.70	0.66	0.17	0.51	Potential Future Vulnerability	NO
Purse Seine	*Halobaena caerulea*	0.70	0.66	0.17	0.51	Potential Future Vulnerability	NO
Purse Seine	*Onychoprion anaethetus*	0.70	0.66	0.17	0.51	Potential Future Vulnerability	NO
Purse Seine	*Pachyptila desolata*	0.70	0.66	0.17	0.51	Potential Future Vulnerability	NO
Purse Seine	*Pachyptila salvini*	0.70	0.66	0.17	0.51	Potential Future Vulnerability	NO
Purse Seine	*Pachyptila vittata*	0.70	0.66	0.17	0.51	Potential Future Vulnerability	NO
Purse Seine	*Onychoprion aleuticus*	0.70	0.66	0.17	0.51	Potential Future Vulnerability	NO
Purse Seine	*Larus michahellis*	0.55	0.46	0.52	0.51	Low Vulnerability	NO
Purse Seine	*Hydrobates leucorhous*	0.50	0.85	0.17	0.51	Low Vulnerability	NO
Purse Seine	*Hydrobates matsudairae*	0.50	0.85	0.17	0.51	Low Vulnerability	NO
Purse Seine	*Rissa tridactyla*	0.63	0.71	0.18	0.51	Potential Future Vulnerability	YES
Purse Seine	*Sula dactylatra*	0.73	0.61	0.18	0.51	Potential Future Vulnerability	NO
Purse Seine	*Sterna hirundinacea*	0.49	0.48	0.55	0.51	Low Vulnerability	NO
Purse Seine	*Phaethon rubricauda*	0.63	0.72	0.17	0.51	Potential Future Vulnerability	NO
Purse Seine	*Uria aalge*	0.63	0.72	0.17	0.51	Potential Future Vulnerability	YES
Purse Seine	*Uria lomvia*	0.63	0.72	0.17	0.51	Potential Future Vulnerability	YES
Purse Seine	*Brachyramphus marmoratus*	0.49	0.85	0.17	0.50	Low Vulnerability	YES
Purse Seine	*Oceanites gracilis*	0.50	0.43	0.57	0.50	Low Vulnerability	NO
Purse Seine	*Oceanites pincoyae*	0.50	0.43	0.57	0.50	Low Vulnerability	NO
Purse Seine	*Larus belcheri*	0.45	0.46	0.59	0.50	Low Vulnerability	NO
Purse Seine	*Pterodroma pycrofti*	0.70	0.80	0.00	0.50	Potential Future Vulnerability	NO
Purse Seine	*Eudyptes sclateri*	0.79	0.71	0.00	0.50	Potential Future Vulnerability	YES
Purse Seine	*Megadyptes antipodes*	0.79	0.71	0.00	0.50	Potential Future Vulnerability	YES
Purse Seine	*Hydrobates markhami*	0.50	0.81	0.18	0.50	Low Vulnerability	NO
Purse Seine	*Larus hemprichii*	0.84	0.48	0.17	0.50	Low Vulnerability	NO
Purse Seine	*Larus leucophthalmus*	0.84	0.48	0.17	0.50	Low Vulnerability	YES
Purse Seine	*Fregetta maoriana*	0.56	0.93	0.00	0.50	Potential Future Vulnerability	NO
Purse Seine	*Pelecanus crispus*	0.79	0.52	0.18	0.49	Low Vulnerability	YES
Purse Seine	*Pagodroma nivea*	0.70	0.77	0.00	0.49	Potential Future Vulnerability	NO
Purse Seine	*Larus serranus*	0.45	0.48	0.55	0.49	Low Vulnerability	NO
Purse Seine	*Pelecanus occidentalis*	0.79	0.51	0.17	0.49	Low Vulnerability	YES
Purse Seine	*Ardenna grisea*	0.45	0.84	0.18	0.49	Low Vulnerability	YES
Purse Seine	*Larus thayeri*	0.84	0.46	0.17	0.49	Low Vulnerability	NO
Purse Seine	*Nesofregetta fuliginosa*	0.56	0.91	0.00	0.49	Potential Future Vulnerability	NO

Purse Seine	*Rynchops albicollis*	0.70	0.59	0.17	0.49	Potential Future Vulnerability	NO
Purse Seine	*Phaethon aethereus*	0.63	0.66	0.17	0.49	Potential Future Vulnerability	NO
Purse Seine	*Phaethon lepturus*	0.63	0.66	0.17	0.49	Potential Future Vulnerability	NO
Purse Seine	*Larus dominicanus*	0.45	0.48	0.53	0.49	Low Vulnerability	NO
Purse Seine	*Oceanites oceanicus*	0.56	0.72	0.18	0.49	Potential Future Vulnerability	NO
Purse Seine	*Fregetta tropica*	0.56	0.72	0.18	0.48	Potential Future Vulnerability	NO
Purse Seine	*Sterna trudeaui*	0.49	0.42	0.55	0.48	Low Vulnerability	NO
Purse Seine	*Sterna hirundo*	0.49	0.48	0.49	0.48	Low Vulnerability	NO
Purse Seine	*Sterna paradisaea*	0.70	0.58	0.17	0.48	Potential Future Vulnerability	YES
Purse Seine	*Fregetta grallaria*	0.56	0.72	0.17	0.48	Potential Future Vulnerability	NO
Purse Seine	*Garrodia nereis*	0.56	0.72	0.17	0.48	Potential Future Vulnerability	NO
Purse Seine	*Pelagodroma marina*	0.56	0.72	0.17	0.48	Potential Future Vulnerability	NO
Purse Seine	*Macronectes giganteus*	0.50	0.77	0.17	0.48	Low Vulnerability	YES
Purse Seine	*Eudyptes chrysolophus*	0.79	0.66	0.00	0.48	Potential Future Vulnerability	YES
Purse Seine	*Eudyptes robustus*	0.79	0.66	0.00	0.48	Potential Future Vulnerability	YES
Purse Seine	*Ardenna carneipes*	0.45	0.81	0.17	0.48	Low Vulnerability	YES
Purse Seine	*Calonectris edwardsii*	0.45	0.81	0.17	0.48	Low Vulnerability	NO
Purse Seine	*Puffinus opisthomelas*	0.45	0.81	0.17	0.48	Low Vulnerability	YES
Purse Seine	*Puffinus lherminieri*	0.49	0.77	0.17	0.48	Low Vulnerability	NO
Purse Seine	*Phalacrocorax nigrogularis*	0.73	0.53	0.17	0.48	Low Vulnerability	YES
Purse Seine	*Hydrobates castro*	0.50	0.75	0.17	0.48	Low Vulnerability	NO
Purse Seine	*Microcarbo coronatus*	0.45	0.40	0.57	0.47	Low Vulnerability	NO
Purse Seine	*Eudyptes schlegeli*	0.79	0.64	0.00	0.47	Potential Future Vulnerability	YES
Purse Seine	*Gygis alba*	0.70	0.72	0.00	0.47	Potential Future Vulnerability	NO
Purse Seine	*Gygis microrhyncha*	0.70	0.72	0.00	0.47	Potential Future Vulnerability	NO
Purse Seine	*Puffinus assimilis*	0.49	0.75	0.17	0.47	Low Vulnerability	NO
Purse Seine	*Puffinus elegans*	0.49	0.75	0.17	0.47	Low Vulnerability	NO
Purse Seine	*Puffinus subalaris*	0.49	0.75	0.17	0.47	Low Vulnerability	NO
Purse Seine	*Hydroprogne caspia*	0.45	0.48	0.49	0.47	Low Vulnerability	NO
Purse Seine	*Larus canus*	0.45	0.37	0.59	0.47	Low Vulnerability	NO
Purse Seine	*Rynchops flavirostris*	0.70	0.54	0.17	0.47	Low Vulnerability	YES
Purse Seine	*Larus hartlaubii*	0.31	0.52	0.57	0.47	Low Vulnerability	NO
Purse Seine	*Larus occidentalis*	0.34	0.51	0.55	0.47	Low Vulnerability	NO
Purse Seine	*Pterodroma inexpectata*	0.45	0.78	0.17	0.47	Low Vulnerability	NO
Purse Seine	*Nannopterum harrisi*	0.79	0.61	0.00	0.47	Potential Future Vulnerability	YES
Purse Seine	*Hydrobates tethys*	0.50	0.72	0.18	0.47	Low Vulnerability	NO
Purse Seine	*Pygoscelis antarcticus*	0.79	0.44	0.17	0.46	Low Vulnerability	YES
Purse Seine	*Hydrobates monteiroi*	0.50	0.89	0.00	0.46	Low Vulnerability	NO

Purse Seine	*Hydrobates furcatus*	0.50	0.72	0.17	0.46	Low Vulnerability	NO
Purse Seine	*Hydrobates melania*	0.50	0.72	0.17	0.46	Low Vulnerability	NO
Purse Seine	*Hydrobates microsoma*	0.50	0.72	0.17	0.46	Low Vulnerability	NO
Purse Seine	*Hydrobates pelagicus*	0.50	0.72	0.17	0.46	Low Vulnerability	NO
Purse Seine	*Hydrobates tristrami*	0.50	0.72	0.17	0.46	Low Vulnerability	NO
Purse Seine	*Puffinus nativitatis*	0.63	0.75	0.00	0.46	Potential Future Vulnerability	NO
Purse Seine	*Sternula nereis*	0.56	0.66	0.17	0.46	Potential Future Vulnerability	NO
Purse Seine	*Puffinus heinrothi*	0.49	0.89	0.00	0.46	Low Vulnerability	NO
Purse Seine	*Ardenna gravis*	0.45	0.75	0.17	0.46	Low Vulnerability	YES
Purse Seine	*Ardenna tenuirostris*	0.45	0.75	0.17	0.46	Low Vulnerability	YES
Purse Seine	*Brachyramphus brevirostris*	0.49	0.72	0.17	0.46	Low Vulnerability	YES
Purse Seine	*Brachyramphus perdix*	0.49	0.72	0.17	0.46	Low Vulnerability	YES
Purse Seine	*Calonectris borealis*	0.45	0.75	0.17	0.46	Low Vulnerability	YES
Purse Seine	*Calonectris diomedea*	0.45	0.75	0.17	0.46	Low Vulnerability	YES
Purse Seine	*Alle alle*	0.49	0.72	0.17	0.46	Low Vulnerability	YES
Purse Seine	*Synthliboramphus hypoleucus*	0.49	0.71	0.17	0.46	Low Vulnerability	YES
Purse Seine	*Pygoscelis papua*	0.79	0.40	0.17	0.45	Low Vulnerability	YES
Purse Seine	*Eudyptes pachyrhynchus*	0.79	0.57	0.00	0.45	Potential Future Vulnerability	YES
Purse Seine	*Onychoprion lunatus*	0.70	0.66	0.00	0.45	Potential Future Vulnerability	NO
Purse Seine	*Leucocarbo atriceps*	0.73	0.46	0.17	0.45	Low Vulnerability	YES
Purse Seine	*Spheniscus mendiculus*	0.73	0.61	0.00	0.45	Potential Future Vulnerability	YES
Purse Seine	*Sula granti*	0.73	0.44	0.17	0.45	Low Vulnerability	NO
Purse Seine	*Catharacta maccormicki*	0.55	0.61	0.17	0.45	Potential Future Vulnerability	NO
Purse Seine	*Thalasseus maximus*	0.63	0.52	0.18	0.44	Low Vulnerability	NO
Purse Seine	*Larus pipixcan*	0.31	0.46	0.55	0.44	Low Vulnerability	NO
Purse Seine	*Synthliboramphus craveri*	0.49	0.66	0.17	0.44	Low Vulnerability	YES
Purse Seine	*Cepphus grylle*	0.63	0.52	0.17	0.44	Low Vulnerability	YES
Purse Seine	*Pelecanoides magellani*	0.49	0.66	0.17	0.44	Low Vulnerability	NO
Purse Seine	*Pelecanoides urinatrix*	0.49	0.66	0.17	0.44	Low Vulnerability	NO
Purse Seine	*Thalasseus bengalensis*	0.49	0.66	0.17	0.44	Low Vulnerability	NO
Purse Seine	*Larus maculipennis*	0.34	0.46	0.52	0.44	Low Vulnerability	NO
Purse Seine	*Leucocarbo onslowi*	0.73	0.59	0.00	0.44	Potential Future Vulnerability	YES
Purse Seine	*Anous albivittus*	0.56	0.58	0.17	0.44	Potential Future Vulnerability	NO
Purse Seine	*Eudyptula minor*	0.73	0.40	0.17	0.43	Low Vulnerability	YES
Purse Seine	*Leucocarbo campbelli*	0.73	0.57	0.00	0.43	Potential Future Vulnerability	NO
Purse Seine	*Leucocarbo carunculatus*	0.73	0.57	0.00	0.43	Potential Future Vulnerability	YES
Purse Seine	*Pygoscelis adeliae*	0.79	0.52	0.00	0.43	Low Vulnerability	YES
Purse Seine	*Phalacrocorax featherstoni*	0.73	0.57	0.00	0.43	Potential Future Vulnerability	YES

Purse Seine	*Rynchops niger*	0.70	0.41	0.18	0.43	Low Vulnerability	NO
Purse Seine	*Larus melanocephalus*	0.31	0.46	0.52	0.43	Low Vulnerability	NO
Purse Seine	*Leucocarbo magellanicus*	0.73	0.37	0.17	0.42	Low Vulnerability	YES
Purse Seine	*Ptychoramphus aleuticus*	0.49	0.60	0.17	0.42	Low Vulnerability	YES
Purse Seine	*Larus ridibundus*	0.31	0.37	0.58	0.42	Low Vulnerability	NO
Purse Seine	*Leucocarbo chalconotus*	0.73	0.53	0.00	0.42	Low Vulnerability	YES
Purse Seine	*Leucocarbo ranfurlyi*	0.73	0.53	0.00	0.42	Low Vulnerability	NO
Purse Seine	*Nannopterum brasilianus*	0.73	0.34	0.18	0.42	Low Vulnerability	NO
Purse Seine	*Rhodostethia rosea*	0.70	0.37	0.17	0.42	Low Vulnerability	NO
Purse Seine	*Puffinus gavia*	0.49	0.75	0.00	0.41	Low Vulnerability	YES
Purse Seine	*Leucocarbo colensoi*	0.73	0.51	0.00	0.41	Low Vulnerability	NO
Purse Seine	*Cepphus carbo*	0.63	0.44	0.17	0.41	Low Vulnerability	YES
Purse Seine	*Cepphus columba*	0.63	0.44	0.17	0.41	Low Vulnerability	YES
Purse Seine	*Gulosus aristotelis*	0.73	0.34	0.17	0.41	Low Vulnerability	YES
Purse Seine	*Nannopterum auritus*	0.73	0.34	0.17	0.41	Low Vulnerability	NO
Purse Seine	*Phalacrocorax varius*	0.73	0.34	0.17	0.41	Low Vulnerability	NO
Purse Seine	*Urile urile*	0.73	0.34	0.17	0.41	Low Vulnerability	NO
Purse Seine	*Aethia cristatella*	0.49	0.58	0.17	0.41	Low Vulnerability	NO
Purse Seine	*Larus argentatus*	0.55	0.51	0.17	0.41	Low Vulnerability	YES
Purse Seine	*Larus glaucescens*	0.55	0.51	0.17	0.41	Low Vulnerability	NO
Purse Seine	*Catharacta antarctica*	0.44	0.61	0.17	0.41	Low Vulnerability	NO
Purse Seine	*Sternula albifrons*	0.17	0.48	0.57	0.40	Low Vulnerability	NO
Purse Seine	*Sterna virgata*	0.49	0.72	0.00	0.40	Low Vulnerability	NO
Purse Seine	*Aethia psittacula*	0.49	0.54	0.17	0.40	Low Vulnerability	NO
Purse Seine	*Aethia pygmaea*	0.49	0.54	0.17	0.40	Low Vulnerability	NO
Purse Seine	*Sternula saundersi*	0.56	0.48	0.17	0.40	Low Vulnerability	NO
Purse Seine	*Larus ichthyaetus*	0.55	0.48	0.17	0.40	Low Vulnerability	NO
Purse Seine	*Thalasseus sandvicensis*	0.49	0.52	0.18	0.40	Low Vulnerability	NO
Purse Seine	*Larus hyperboreus*	0.55	0.46	0.18	0.40	Low Vulnerability	NO
Purse Seine	*Sterna sumatrana*	0.49	0.52	0.18	0.40	Low Vulnerability	NO
Purse Seine	*Sterna vittata*	0.49	0.52	0.17	0.39	Low Vulnerability	NO
Purse Seine	*Larus cachinnans*	0.55	0.46	0.17	0.39	Low Vulnerability	NO
Purse Seine	*Larus livens*	0.55	0.46	0.17	0.39	Low Vulnerability	NO
Purse Seine	*Sterna aurantia*	0.49	0.52	0.17	0.39	Low Vulnerability	NO
Purse Seine	*Phalacrocorax fuscescens*	0.73	0.44	0.00	0.39	Low Vulnerability	NO
Purse Seine	*Larus heermanni*	0.45	0.54	0.17	0.39	Low Vulnerability	YES
Purse Seine	*Larus relictus*	0.45	0.53	0.17	0.39	Low Vulnerability	NO
Purse Seine	*Pelecanoides georgicus*	0.49	0.66	0.00	0.38	Low Vulnerability	NO

Purse Seine	*Pachyptila turtur*	0.31	0.66	0.17	0.38	Low Vulnerability	NO
Purse Seine	*Larus armenicus*	0.45	0.52	0.17	0.38	Low Vulnerability	NO
Purse Seine	*Anous ceruleus*	0.56	0.58	0.00	0.38	Potential Future Vulnerability	NO
Purse Seine	*Sterna acuticauda*	0.31	0.65	0.17	0.38	Low Vulnerability	YES
Purse Seine	*Phalacrocorax fuscicollis*	0.63	0.33	0.17	0.38	Low Vulnerability	NO
Purse Seine	*Phalacrocorax sulcirostris*	0.63	0.33	0.17	0.38	Low Vulnerability	NO
Purse Seine	*Sterna forsteri*	0.49	0.46	0.17	0.37	Low Vulnerability	NO
Purse Seine	*Chlidonias niger*	0.56	0.37	0.18	0.37	Low Vulnerability	NO
Purse Seine	*Larus cirrocephalus*	0.45	0.48	0.18	0.37	Low Vulnerability	NO
Purse Seine	*Phalacrocorax punctatus*	0.73	0.37	0.00	0.37	Low Vulnerability	NO
Purse Seine	*Larus brunnicephalus*	0.45	0.48	0.17	0.37	Low Vulnerability	NO
Purse Seine	*Larus glaucoides*	0.45	0.48	0.17	0.37	Low Vulnerability	NO
Purse Seine	*Stercorarius parasiticus*	0.34	0.58	0.18	0.37	Low Vulnerability	NO
Purse Seine	*Stercorarius pomarinus*	0.34	0.58	0.18	0.37	Low Vulnerability	NO
Purse Seine	*Pagophila eburnea*	0.34	0.58	0.17	0.36	Low Vulnerability	NO
Purse Seine	*Sterna striata*	0.49	0.58	0.00	0.36	Low Vulnerability	NO
Purse Seine	*Larus marinus*	0.44	0.46	0.17	0.36	Low Vulnerability	YES
Purse Seine	*Aethia pusilla*	0.35	0.54	0.17	0.35	Low Vulnerability	NO
Purse Seine	*Sterna repressa*	0.35	0.52	0.17	0.35	Low Vulnerability	NO
Purse Seine	*Chlidonias hybrida*	0.17	0.37	0.49	0.34	Low Vulnerability	NO
Purse Seine	*Microcarbo niger*	0.45	0.37	0.17	0.33	Low Vulnerability	NO
Purse Seine	*Larus fuliginosus*	0.45	0.53	0.00	0.33	Low Vulnerability	YES
Purse Seine	*Pachyptila crassirostris*	0.31	0.66	0.00	0.32	Low Vulnerability	NO
Purse Seine	*Larus californicus*	0.34	0.46	0.17	0.32	Low Vulnerability	NO
Purse Seine	*Larus delawarensis*	0.34	0.46	0.17	0.32	Low Vulnerability	NO
Purse Seine	*Larus novaehollandiae*	0.31	0.48	0.17	0.32	Low Vulnerability	NO
Purse Seine	*Phaetusa simplex*	0.31	0.48	0.17	0.32	Low Vulnerability	NO
Purse Seine	*Microcarbo africanus*	0.45	0.33	0.17	0.32	Low Vulnerability	YES
Purse Seine	*Microcarbo melanoleucos*	0.45	0.33	0.17	0.32	Low Vulnerability	NO
Purse Seine	*Hydrocoloeus minutus*	0.31	0.46	0.18	0.32	Low Vulnerability	NO
Purse Seine	*Larus atricilla*	0.31	0.46	0.18	0.32	Low Vulnerability	NO
Purse Seine	*Larus genei*	0.31	0.46	0.18	0.32	Low Vulnerability	NO
Purse Seine	*Larus philadelphia*	0.31	0.46	0.17	0.31	Low Vulnerability	NO
Purse Seine	*Gelochelidon nilotica*	0.31	0.42	0.18	0.30	Low Vulnerability	NO
Purse Seine	*Larus bulleri*	0.20	0.71	0.00	0.30	Low Vulnerability	NO
Purse Seine	*Stercorarius longicaudus*	0.20	0.52	0.17	0.30	Low Vulnerability	NO
Purse Seine	*Sternula antillarum*	0.17	0.48	0.17	0.27	Low Vulnerability	NO
Purse Seine	*Sternula superciliaris*	0.17	0.48	0.17	0.27	Low Vulnerability	NO

Purse Seine	*Chlidonias albostriatus*	0.17	0.65	0.00	0.27	Low Vulnerability	NO
Purse Seine	*Xema sabini*	0.20	0.36	0.17	0.25	Low Vulnerability	NO
Purse Seine	*Chlidonias leucopterus*	0.17	0.37	0.18	0.24	Low Vulnerability	NO