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ARTICLE

Patterns of uncertainty in life-history and extinction risk for Arctic vertebrates

Cody J. Dey, David J. Yurkowski, Richard Schuster, David S. Shiffman, and Sarah Joy Bittick

Abstract: Conserving Arctic wildlife will be challenging given the ongoing environmental changes in the region. In addition, there is a lack of fundamental biological information for many Arctic species, including a dearth of knowledge surrounding conservation threats and the risk of extinction. In this study, we gather all available data on research effort and life-history traits to assess the current state of scientific knowledge surrounding 389 Arctic vertebrate species. We also quantify patterns of species evaluation by the IUCN Red List, a global database of conservation risk used to measure success and prioritize resources in many conservation programs. We find that 10% of Arctic vertebrates have been the subject of no peer-reviewed studies during the last 30 years, and that we have little life history knowledge for many species. Arctic marine fishes are especially poorly known with an average of 3.5 (out of six) key life-history traits unknown. In a multivariate analysis, whether an Arctic species had been evaluated by the IUCN Red List was most strongly predicted by research effort and varied among taxonomic groups. In addition, we found that species that have been evaluated by the IUCN Red List continue to receive more research attention than species which have not been evaluated. Protecting all Arctic species may, therefore, require research programs and methods to halt research inertia and shift more attention onto species that are poorly known.

Key words: threatened species, conservation, Red List.

Résumé : La conservation d'espèces sauvages constituera un défi étant donné les changements environnementaux en cours dans la région. De plus, il y a un manque d'informations biologiques fondamentales à propos d'un grand nombre d'espèces de l'Arctique, y compris un manque de connaissances entourant les menaces relatives à la conservation et le risque d'extinction. Dans le cadre de cette étude, nous rassemblons toutes les données disponibles au sujet des efforts de recherche et des attributs d'histoire de vie afin d'évaluer l'état actuel des connaissances scientifiques entourant 389 espèces vertébrées de l'Arctique. Nous quantifions aussi les modèles d'évaluation des espèces par la liste rouge de l'Union

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Internationale pour la Conservation de la Nature (UICN), une base de données mondiale des menaces liées à la conservation utilisée pour mesurer le succès et prioriser les ressources de nombreux programmes de conservation. Nous constatons que 10 % des vertébrés arctiques n'ont fait l'objet d'aucune étude examinée par des pairs au cours des 30 dernières années et que nous avons peu de connaissances de l'histoire de vie d'un grand nombre d'espèces. On connaît particulièrement mal les poissons marins de l'Arctique puisqu'une moyenne de 3,5 (sur 6) des grands traits d'histoire de vie sont inconnus. Dans une analyse multivariée, la question à savoir si une espèce arctique avait été évaluée par la liste rouge UICN était étroitement liée à l'effort de recherche et variait parmi les groupes taxonomiques. De plus, nous avons constaté que les espèces qui ont été évaluées par la liste rouge UICN continuent de recevoir plus d'attention de recherche que les espèces qui n'ont pas été évaluées. Protéger toutes les espèces de l'Arctique pourra donc nécessiter des programmes et des méthodes de recherche afin de mettre un terme à l'inertie de recherche et d'accorder plus d'attention aux espèces qui sont mal connues. [Traduit par la Rédaction]

Mots-clés : espèce menacée, conservation, liste rouge.

Introduction

The Arctic is composed of unique ecological communities considered to be among the earth's most biologically valuable areas (Olson and Dinerstein 1998). Yet, the conditions in northern polar areas present unique challenges for conservation. Large areas of Arctic wilderness are still intact (i.e., undisturbed by industrialized human development and transportation; Sanderson et al. 2002; Venter et al. 2016), but the Arctic is experiencing rapid climatic change, including greater climate warming than any other area of earth (Hansen et al. 2006). In addition, human activity in the Arctic is projected to dramatically increase as the loss of sea ice opens shipping corridors and allows increased industrial activity (Stephenson et al. 2011). Conserving Arctic wildlife in the face of these environmental changes will be difficult.

Although Arctic wildlife has been the focus of considerable conservation efforts, a major challenge in conservation decision-making in northern polar areas is a lack of population, demographic, geographical, and basic life-history data for many Arctic animals. Indeed, this scarcity of information was highlighted in the 2013 Assessment of Arctic Biodiversity (CAFF 2013) which stated, *"Basic knowledge on the vast majority of Arctic biodiversity is limited"* (p. 57), and *"There are no abundance or trend estimates for many key populations and species"* (p. 122). In many cases, local knowledge can address gaps in scientific understanding (Huntington 2000; Gilchrist et al. 2005). However, conservation success is thought to be maximized when local and scientific knowledge are both integrated in conservation plans (Becker and Ghimire 2003; Kainer et al. 2009). As such, a lack of scientific knowledge of Arctic species poses a problem for biodiversity conservation.

In addition to an overall lack of data, it is possible that research effort for Arctic animals is biased towards certain fauna. For example, certain charismatic species may be highly studied because of taxonomic biases in research funding (Tisdell and Nantha 2007; Fisher et al. 2011). Similarly, species that are frequently harvested may be relatively well understood because harvest programs provide a source of data (e.g., demography and population data, samples, etc.) that would not otherwise be available. Such biases pattern would not be surprising, given that global research effort shows geographical and taxonomical biases, biases towards larger species, and biases towards less endangered species (Brodie 2009; De Lima et al. 2011; Fisher et al. 2011; Brooke et al. 2014; Jaric et al. 2015). However, such patterns could be exacerbated in the Arctic because of the remoteness of many Arctic areas, the high cost of Arctic research (Mallory et al. 2018), and the importance of subsistence harvest of predominantly large-bodied species.

In this study, we compiled data on research effort and key life-history traits for 389 Arctic vertebrates. In addition, we collected data on IUCN Red List (IUCN 2017) evaluations to understand what factors determine whether a species has been evaluated by this program. The IUCN Red List is an objective, scientifically rigorous global database of conservation risk for species (IUCN 2017). Although many vertebrates have been evaluated (67% of global vertebrate species; IUCN Red List v. 2017-3 Table 1), there is considerable variation related to taxonomy and geography (IUCN Red List v. 2017-3 Table 1). These gaps in the IUCN Red List are important to understand because Red List data are used for a variety of international, national, and regional conservation initiatives (Gärdenfors et al. 2011), measure progress in the Convention on Biological Diversity Aichi Targets (CBD-AHTEG 2015), inform the Convention on International Trade in Endangered Species and the Convention on Migratory Species (UNEP-WCMC 2013; UNEP 2015), and influence resource allocation for research and conservation (Possingham et al. 2002). Species that have not been evaluated by the IUCN Red List will therefore not count towards the measurement of success in these programs, potentially imposing different conservation value on different species.

In this study, we address the following two primary research questions: (1) what is the state of scientific knowledge surrounding Arctic vertebrates, and how is scientific knowledge related to species traits and taxonomy? and (2) what factors drive IUCN Red List evaluation for Arctic vertebrates? By answering these questions, we hope to improve our understanding of conservation uncertainty for Arctic vertebrates and ultimately enhance biodiversity conservation in Arctic regions.

Methods

Data collection

For this study, we collected data from the peer-reviewed literature and readily available secondary sources (i.e., field guides and handbooks, online databases) for a suite of life history and conservation-related traits, for each of 389 Arctic vertebrates. Full details related to the data collection, including details related to species inclusion, are provided in the Supplementary Materials.[1]

In brief, we collected data from hardcopy and electronic databases for as many species as possible related to (*i*) primary habitat — classified as either marine, terrestrial or freshwater, (*ii*) current IUCN Red List status — with possible values of Least Concern, Near Threatened, Vulnerable, Endangered, Critically Endangered, Extinct in the Wild, Extinct, in increasing order of extinction risk, (*iii*) year of the most recent IUCN Red List assessment, (*iv*) number of threats — measured as the number of threats to the species listed in the IUCN Red List threat classification scheme, (*v*–*viii*) binary scores of whether each species is threatened by climate change, habitat alteration, invasive species, or overexploitation, respectively, (*ix*) adult body mass, (*x*) maximum longevity, (*xi*) age of female maturity, (*xii*) fecundity, (*xiii*) reproductive rate, and (*xiv*) trophic level. These life-history traits (*ix*–*xiv*) were chosen because they are important variables driving population dynamics and because they are commonly reported in secondary sources. If separate values were reported for males and females (e.g., for variables *ix*, *x*), we recorded the mean of the values. If a range of values was reported (e.g., for variables *ix*–*xiv*), we recorded the center of the range.

In addition, we provide data on (*xv*) research effort, measured as the number of papers published on each species between 1987 and 2016 that were archived on Web of Science (Clarivate Analytics 2017). This metric includes research conducted outside of the Arctic

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[1] Supplementary material is available with the article through the journal Web site at http://nrcresearchpress.com/doi/suppl/10.1139/as-2018-0006.

Table 1. Sources used to compile the dataset used in this study.

Rank	Source	Citation	Taxa	Data types
1	IUCN Red List	IUCN 2017	All	*i–viii, xvi*
2	Web of Science	Clarivate Analytics 2017	All	*xv*
3	Fishbase	Froese and Pauly 2017	Fishes	*ix–xii*
4	AmphiBIO	Oliveira et al. 2017	Amphibians	*ix–xii*
5	AnAge Database	Tacutu et al. 2013	All	*ix–xii*
6	Amniote Trait Database	Myhrvold et al. 2015	Birds, mammals	*ix–xii*
7	Animal Diversity Web	Myers et al. 2017	All	*xii, ix*
8	The Arctic Guide	Chester 2016	All	*i*
9	Arctic Biodiversity Assessment	CAFF 2013	All	*xiv*
10	EltonTraits	Wilman et al. 2014	Birds, mammals	*xiv*
11	Marine fishes of the Arctic Region	Mecklenburg et al. 2018	Marine fishes	*ix, x, xii*

Note: The data types column describes which data types were taken from each source, and refer to the 15 data types described in the "Data collection" subsection of the "Methods".

region, which we permitted because conservation decision-making often draws on information from outside the focal region. As such, there is a stronger scientific basis for managing Arctic species that are well researched even if that research occurs outside of the Arctic, compared with species that are not well studied. Finally, we collected data on the (*xvi*) history of IUCN assessments for each species in our data set, including the year and IUCN Red List conservation threat level of all previous evaluations.

Data sources were ranked (see Table 1) and data collected in an iterative fashion; we first searched the highest-ranking sources (i.e., those judged to be highly reliable and to contain many data points required for our analyses). If data were found in a high-ranking source, we no longer searched for this value in the remaining sources. This approach facilitated a progressive reduction in "missing data" in our database and allowed the searching of increasingly specialized sources.

The data from this study are publicly available at doi.org/10.5281/zenodo.1149680 (Dey et al. 2018). Note that we do not use all of the data collected as part of the analysis described below, but we provide all of the data collected for the use of other researchers.

Statistical analysis — taxonomic patterns

We first explored general patterns of research effort and trait knowledge across all species using descriptive statistics. Then, we tested for differences in total research effort among taxonomic groups. We classified animals into six taxonomic groups [marine mammals, terrestrial mammals, marine birds, terrestrial birds, marine fishes, freshwater fishes (amphibians were excluded from this and all subsequent analyses as there were only three species in our dataset)] based on their primary habitat use (i.e., trait *i*, above) and taxonomic classification.

Because the processes driving the number of published papers were unknown, we used model selection to select among models which all included the total number of publications as the response variable and taxonomic group as the sole fixed effect. During exploratory data analysis, we noticed that a large number of species had zero published papers, and that the number of papers published per species was overdispersed relative to a Poisson distribution. As such, we formulated all of our models with negative binomial error structures (Table 2).

The models we selected among were (a) a negative binomial generalized linear model (nbGLM), (b) a zero-inflated nbGLM with a single intercept for zero-inflation, (c) a zero-inflated nbGLM with a fixed effect of taxonomic group for zero-inflation, (d) a hurdle nbGLM with a single intercept for zero-inflation, and (e) a hurdle nbGLM with a fixed

Table 2. Models analyzing the relationship between number of published papers (response variable) and taxonomic group (fixed effect).

Model	AIC	df	Log-likelihood	Zero component?
GLM	4539	7	−2263	—
Zero-inflated 1	4541	8	−2263	Intercept only
Zero-inflated 2	4527	13	−2251	Taxonomic group
Hurdle 1	4508	8	−2246	Intercept only
Hurdle 2	4458	13	−2216	Taxonomic group

Note: The best model was determined by the Akaike information criterion (AIC).

effect of taxonomic group for zero-inflation. In each model, we included taxonomic group as the sole fixed effect.

Next, we tested for taxonomic differences in trait knowledge and IUCN evaluation using two binomial family GLMs. These used the number of known life-history traits, or a binary score of whether a species was Red List evaluated, as the respective response variables, and included taxonomic group as the sole fixed effect. In the latter case, species that were listed under the Red List as Data Deficient were categorized as not evaluated.

Statistical analysis — research effort

Then, we examined how Red List evaluation and taxonomic grouping influenced changes in research effort over time using a negative binomial generalized linear mixed model. In this model, we used the number of papers published in each year for each species as the response variable. The fixed effects included year, taxonomic group, and whether a species had yet been evaluated by the Red List (in the given year). For example, if a species was first evaluated in 2004, all observations for this species up to 2004 would be scored as "Not Evaluated", whereas observations after 2004 would be classified as "Evaluated". To test how research effort changed in different taxonomic groups over time, we included the interaction of group and year in our model. To test how research effort changed over time as a factor of Red List status, we included the interaction of status and year in our model. To account for repeated sampling, we also included a random intercept for each species.

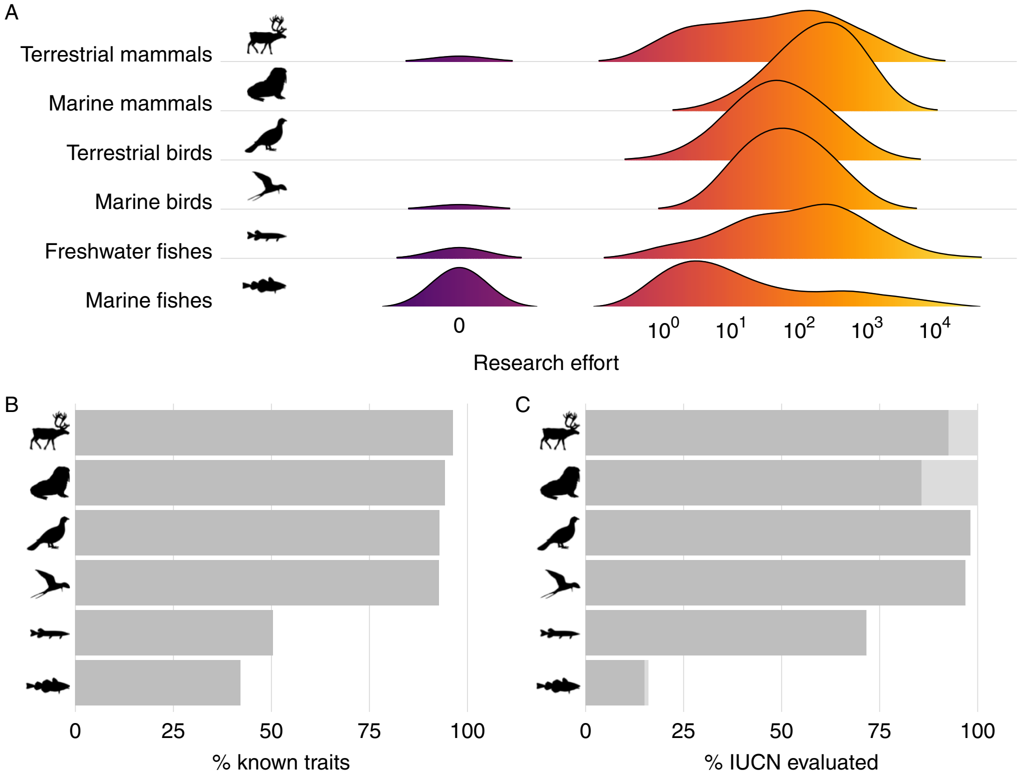
Statistical analysis – Red List evaluation

Finally, we performed a multivariate analysis of factors predicting Red List evaluation. This model was constructed as a binomial family generalized linear mixed model, with log10 (research effort + 0.1), number of known life-history traits, log10 (body mass) and trophic level as predictor variables. The response variable was a binary score of whether a species had been evaluated or not (the latter category included Data Deficient species). To control for differences in evaluation among taxonomic groups, taxonomic group was included as a random intercept.

Results

Across 389 Arctic species in our database, the median number of papers published from 1987 to 2016 was 42 (range: 0–18 679). One hundred and eleven species in our database (29%) have been the subject of fewer than 10 published papers, and 37 species (10%) have been the subject of zero published papers (Fig. 1A) over the 30-year period. The median number of life-history traits known for each species was 4 (range: 0–6). For 32 species (8%), four or more life-history traits were unknown. Two hundred and sixty-six species (68%) have been evaluated by the Red List.

Fig. 1. The state of scientific knowledge of Arctic vertebrates. Panel A shows the density distribution (i.e., total area under the curve is equal for all groups) of research effort (number of papers published from 1987 to 2016) for six groups of Arctic animals. This panel demonstrates a large number of marine fishes have not been the subject of a published study, which is reflected in a low percentage of known life-history traits (body mass, longevity, age at maturity, fecundity, reproductive rate, and trophic level) for marine fishes in our database (B) and a low percentage of species being evaluated for extinction risk in the IUCN Red List (C). Note, light grey coloring in C indicates species evaluated as "Data Deficient". Sample size for each group is as follows: terrestrial mammals (27), marine mammals (35), terrestrial birds (105), marine birds (32), freshwater fishes (81), and marine fishes (106). Animal silhouettes accessed through PhyloPic 2018 via public domain dedication licensing.



Taxonomic patterns

We found considerable taxonomic bias in research effort, with marine fish species being the most likely to have no publications [28%: Fig. 1A; Table 3 (hurdle component)]. For species with at least one published paper, fish species, along with marine mammals, had the highest number of mean publications [freshwater fishes = 655 papers/species; marine fishes = 559 papers/species; marine mammals = 326 papers/species; Fig. 1A; Table 3 (count component)]. In addition, there was relatively low life-history knowledge for fishes and relatively high life-history knowledge for mammals (Fig. 1B; Supplementary Fig. S1[1]; Table 3). Although most (68%) Arctic vertebrates have been evaluated through the Red List, only 15% of Arctic marine fishes have been evaluated, which is much lower than for other taxa (Fig. 1C; Table 3).

Research effort

Research effort on Arctic vertebrates has generally increased from 1987 to 2016 (effect of year, Table 4; Fig. 2B). However, research effort has increased significantly faster for certain taxonomic groups. After controlling for the confounding effect of Red List evaluation, our

Table 3. Statistical modelling results for a relationship between taxonomic group (predictor variables) and measures of the state of knowledge (response variables).

Response	Group	Estimate	95% CI	*P* value
Research effort (count component)	Intercept (terrestrial birds)	4.42	4.00 to 4.86	<0.001
	Marine birds	0.02	−0.80 to 0.84	0.96
	Terrestrial mammals	0.76	−0.13 to 1.65	0.09
	Marine mammals	1.03	0.23 to 1.82	0.01
	Marine fishes	1.60	0.99 to 2.22	<0.001
	Freshwater fishes	1.77	1.15 to 2.39	<0.001
Research effort (hurdle component)	Intercept (marine fishes)	0.98	0.55 to 1.40	<0.001
	Freshwater fishes	1.55	0.61 to 2.48	0.001
	Terrestrial mammals	2.28	0.24 to 4.32	0.03
	Marine birds	2.46	0.42 to 4.49	0.02
	Marine mammals	18.59*	−5.9E3 to 5.9E3*	0.99*
	Terrestrial birds	18.59*	−3.4E3 to 3.4E3*	0.99*
Trait knowledge	Intercept (marine fishes)	−0.31	−0.48 to −0.16	<0.001
	Freshwater fishes	0.33	0.10 to 0.57	0.006
	Marine birds	2.86	2.33 to 3.47	<0.001
	Terrestrial birds	2.88	2.55 to 3.23	<0.001
	Marine mammals	3.12	2.56 to 3.78	<0.001
	Terrestrial mammals	3.58	2.83 to 4.52	<0.001
IUCN evaluation	Intercept (marine fishes)	−1.73	−2.30 to −1.22	<0.001
	Freshwater fishes	2.65	1.96 to 3.40	<0.001
	Marine mammals	3.52	2.51 to 4.71	<0.001
	Terrestrial mammals	4.25	2.92 to 6.14	<0.001
	Marine birds	5.16	3.52 to 8.08	<0.001
	Terrestrial birds	5.67	4.39 to 7.53	<0.001

Note: Raw model estimates are reported along with the 95% confidence intervals (CI). Details of the statistical analysis are presented in the methods. *, because of complete separation (Albert and Anderson 1984), these estimates, confidence intervals and *P* values are unreliable.

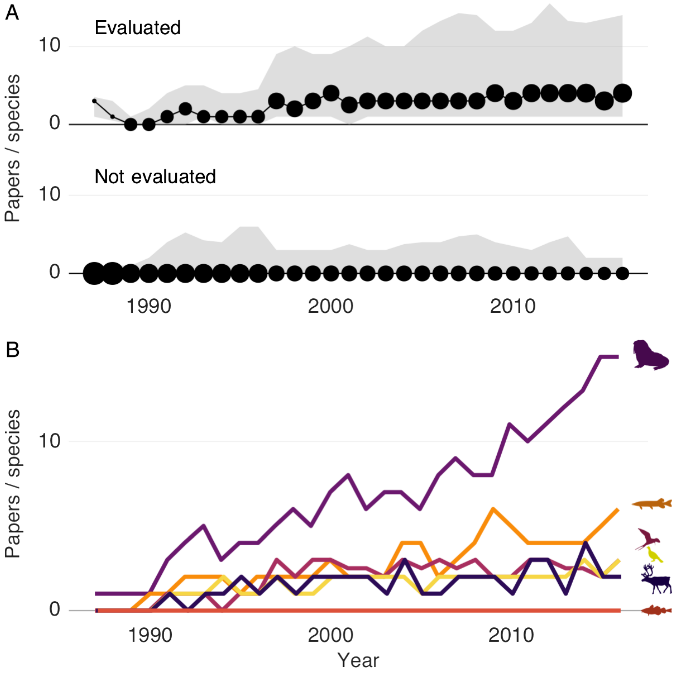
Table 4. Predictors of per year research effort for Arctic vertebrates in this study.

Group	Estimate	95% CI	*P* value
Intercept	−1.83	−2.30 to −1.36	<0.001
Main effects			
Year	1.14	0.93 to 1.36	<0.001
Status (evaluated)	0.08	0.03 to 0.13	0.002
Group (terrestrial mammals)	1.98	1.00 to 2.97	<0.001
Group (terrestrial birds)	2.25	1.61 to 2.89	<0.001
Group (freshwater fishes)	2.51	1.82 to 3.19	<0.001
Group (marine birds)	2.30	1.38 to 3.21	<0.001
Group (marine mammals)	3.51	2.63 to 4.40	<0.001
Interaction effects			
Year × evaluated	−0.88	−0.96 to −0.81	<0.001
Year × terrestrial mammals	0.34	0.02 to 0.65	0.04
Year × terrestrial birds	0.31	0.07 to 0.55	0.01
Year × freshwater fishes	0.17	−0.06 to 0.40	0.15
Year × marine birds	0.45	0.16 to 0.75	0.003
Year × marine mammals	0.64	0.36 to 0.92	<0.001

Note: Raw model estimates are reported along with the 95% confidence intervals (CI). The intercept term represents a reference level with status = not evaluated and group = marine fishes. Details of the statistical analysis are presented in the methods.

analysis shows that publications on marine and terrestrial mammals, as well as marine and terrestrial birds, have increased faster than have publications on marine fishes [Table 4 (interaction effects)]. In addition, there are significantly more papers on species which have

Fig. 2. Changes in research effort for Arctic vertebrates from 1987 to 2016. Panel A shows the changes in median papers per species (line and dots) for species evaluated and not evaluated through the IUCN Red List, respectively. Dot size is scaled to the number of species in each category, and the interquartile range is shown in grey. Note that dot size changes across years in panel A because species can move from "Not Evaluated" to "Evaluated" during the time series. Panel B shows the changes in median papers per species for each of six taxonomic groups, which are indicated by icons on the right. Animal silhouettes accessed through PhyloPic 2018 via public domain dedication licensing.



been evaluated through the Red List compared with species that are not evaluated [Table 4 (main effects); Fig. 2A]. However, the number of studies on evaluated species has increased more slowly than species that are not evaluated [Table 4 (interaction effect)].

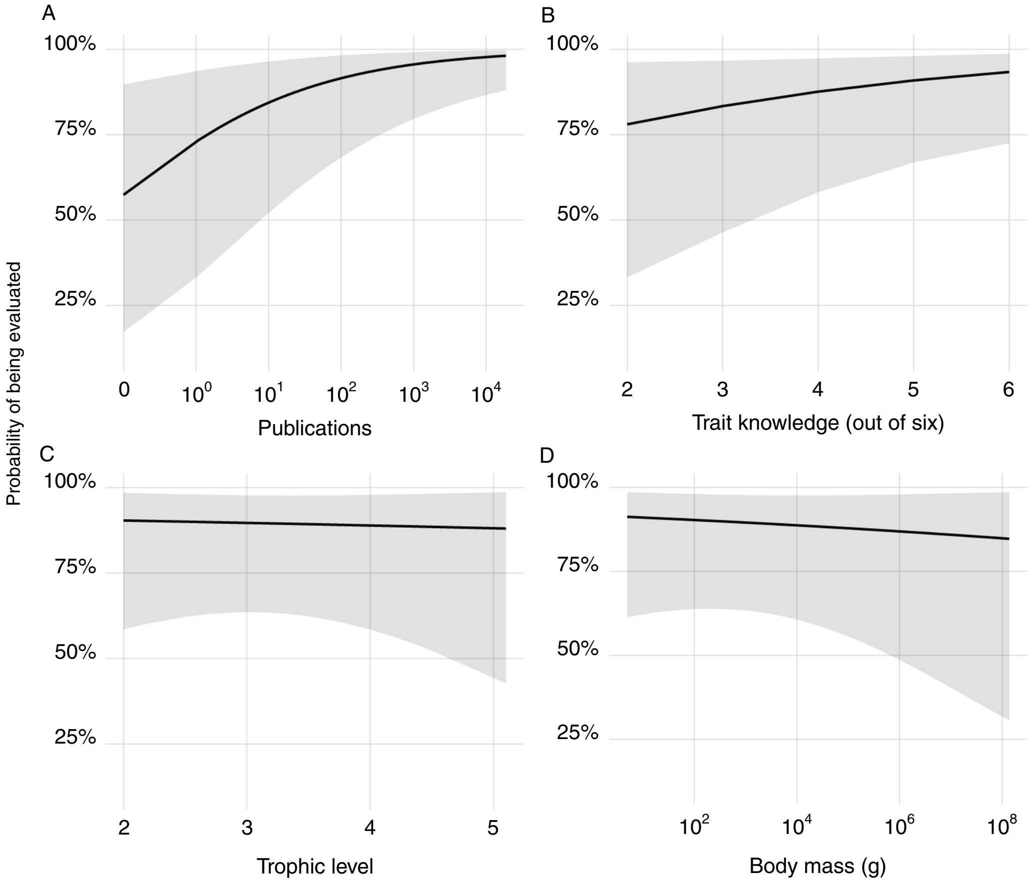
Red List evaluation

After controlling for taxonomic group, Red List evaluation was significantly predicted by research effort, with more research effort increasing the likelihood that a species has been evaluated (Fig. 3A). No other variable included in our model was a significant predictor of Red List evaluation (Fig. 3).

Discussion

Although some Arctic vertebrates are well studied, many have never been the subject of a published scientific study. In addition, nearly one-third of Arctic vertebrates have not been evaluated by the IUCN Red List and we lack fundamental life-history data for many of these species. While these patterns were generally known prior to this study, we provide the first quantification of the scientific knowledge scarcity for Arctic species and identify patterns of conservation uncertainty present in Arctic regions. In addition, we demonstrate a strong relationship between research effort and IUCN Red List evaluation for Arctic vertebrates. Our analysis shows that species are more likely to be evaluated through the Red List if they have been the subject of more published studies (Fig. 3A). However, species that have already been evaluated receive more research effort

Fig. 3. Predictors of whether a species has been evaluated by the IUCN Red List. In each panel, the black line indicates the marginal effect from the binomial generalized linear model, whereas the grey area indicates the 95% confidence interval. Number of publications [estimate (95% CI) = 0.69 (0.30 to 1.12), $P < 0.001$] was significantly related to Red List evaluation, whereas life-history knowledge [estimate (95% CI) = 0.34 (−0.08 to 0.77), $P = 0.10$], trophic level [estimate (95% CI) = −0.08 (−0.97 to 0.81), $P = 0.85$] and body mass [estimate = (95% CI) = −0.08 (−0.48 to 0.33), $P = 0.68$] were not.



than unevaluated species (Fig. 2A). These findings suggest that shifting research focus onto species that are not currently evaluated would help to address data gaps that hinder conservation assessments.

For example, we show that there is relatively little biological and conservation knowledge of Arctic marine fishes. Although approximately 40% of global marine fishes have been evaluated by the Red List (IUCN 2017), we found that only 15% of Arctic marine fishes have been evaluated. In addition, 54% of Arctic marine fishes have been the subject of fewer than five scientific papers published, and we have a poor understanding of reproductive life-history of many species (Supplementary Fig. S1[1]). This is worrying given that commercial fishing in Arctic regions is expected to increase in the near future (Mcbride et al. 2014), and that Arctic marine environments are being invaded by poleward range expansions of southern species (Fossheim et al. 2015). Furthermore, some Arctic marine fishes are known to be keystone species (e.g., Arctic cod; Welch et al. 1992), which play an integral role in mobilizing energy from low to high trophic levels in Arctic food webs, and it is possible that some of the poorly studied species have similarly important roles in

Arctic ecosystems. As such, protection of poorly studied Arctic marine fishes may be essential to maintain populations of higher trophic level species. Interestingly, some Arctic marine fishes are among the most well-studied Arctic vertebrates (e.g., many salmonids and cyprinids), perhaps because of their popularity for recreational angling, aquaculture and commercial harvest both within and outside of the Arctic. Although research effort should not only serve to address conservation needs, increased attention on understudied Arctic marine fishes is clearly warranted.

Evaluation of species through the IUCN Red List is coordinated by a number of Red List Authorities and Global Species Assessment Projects, which represent different taxa and geographic areas. For example, between 2005 and 2015, the IUCN Species Program Marine Biodiversity Unit coordinated efforts to have 20 000 marine vertebrates, invertebrates, plants, and corals evaluated through the IUCN Red List. Although this group outlined priority regions for species evaluations (e.g., the Gulf of Mexico, the Arabian Gulf), the Arctic was not among these regions. As our study shows Arctic fishes (both marine and freshwater) are poorly represented in the Red List and should be a priority for future evaluations. Fortunately, there is already an expert group related to Arctic fishes established through the Arctic Council (the Fishes Expert Network), which could be engaged by the IUCN as a partner in these evaluations. However, to accomplish these evaluations, we will also require increased biological information for many species.

Depending on the true extinction risk of species that are not currently evaluated, somewhere between 9% and 41% of Arctic vertebrates are threatened with extinction (this study). These extremes paint very different pictures of the status of Arctic biodiversity and suggest that dealing with uncertainty in the risk of extinction will be required for Arctic conservation projects in the near-term. In general, researchers suggest using a precautionary principle for unevaluated species (i.e., treating them as Threatened) when considering conservation offsets and mitigation measures (Mace et al. 2008; Butchart and Bird 2010). However, treating unevaluated species as Threatened is not appropriate during protected areas planning processes because it de-values protection of species known to be Threatened and potentially protects areas of low biodiversity value (Butchart and Bird 2010). Regardless of how current uncertainty is approached, it would clearly be beneficial to reduce uncertainty in species conservation risk by prioritizing research effort for unevaluated species. However, our study demonstrates that unevaluated Arctic vertebrates receive lower research effort than species that have been evaluated (Fig. 2A; Table 4). Addressing this bias in research effort would decrease conservation uncertainty and increase the success of Arctic biodiversity conservation.

The Arctic is one of the most ecologically intact places left on earth (Sanderson et al. 2002), and conservation of Arctic species is therefore of global importance. Although there is a current thrust to protect Arctic ecosystems as part of international obligations to meet the Convention on Biological Diversity Aichi Targets (CBD-AHTEG 2015), these measures may be ineffective if they are not informed by scientific knowledge of local species. To maintain Arctic socio-ecosystems, we need further study of many Arctic animals; in particular, we call for increased research effort for Arctic marine fishes, some of which are virtually unknown to science beyond taxonomic identification. Local ecological knowledge could help address gaps in scientific knowledge and should always be considered during conservation planning. However, severe research biases should also be addressed within scientific funding schemes to gain an understanding of the basic biology of all Arctic vertebrates, which will help to effectively conserve biodiversity across this unique environment.

Author contributions

Designed the study: CJD with help from DJY, DSS, and SJB. Collected the data: CJD, DJY, RS, DSS, and SJB. Performed the analysis: CJD and RS. Wrote the manuscript: CJD with help from DJY, RS, DSS, and SJB.

Conflict of interest

The authors have no conflicts of interest to report.

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