Marine Policy 65 (2016) 107–114

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Using expert elicitation to estimate the impacts of plastic pollution on marine wildlife

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ARTICLE INFO

Article history:
Received 9 July 2015
Received in revised form
22 October 2015
Accepted 23 October 2015
Available online 31 October 2015

Keywords:
Chemical contamination
Elicitation survey
Entanglement
Ingestion
Marine debris
Marine mammal
Plastic pollution
Seabird
Turtle

ABSTRACT

Marine litter is a growing environmental concern. With the rapid increase in global plastics production and the resulting large volume of litter that enters the marine environment, determining the consequences of this debris on marine fauna and ocean health has now become a critical environmental priority, particularly for threatened and endangered species. However, there are limited data about the impacts of debris on marine species from which to draw conclusions about the population consequences of anthropogenic debris. To address this knowledge gap, information was elicited from experts on the ecological threat (both severity and specificity) of entanglement, ingestion and chemical contamination for three major marine taxa: seabirds, sea turtles and marine mammals. The threat assessment focused on the most common types of litter that are found along the world's coastlines, based on data gathered during three decades of international coastal clean-up efforts. Fishing related gear, balloons and plastic bags were estimated to pose the greatest entanglement risk to marine fauna. In contrast, experts identified a broader suite of items of concern for ingestion, with plastic bags and plastic utensils ranked as the greatest threats. Entanglement and ingestion affected a similar range of taxa, although entanglement was rated as slightly worse because it is more likely to be lethal. Contamination was scored the lowest in terms of impact, affecting a smaller portion of the taxa and being rated as having solely non-lethal impacts. This work points towards a number of opportunities both for policy-based and consumer-driven changes in plastics use that could have demonstrable affects for a range of ecologically important taxa that serve as indicators of marine ecosystem health.

1. Introduction

Marine litter, and in particular plastic waste, is a growing environmental concern due to its aesthetic, economic, and ecological impacts. Volunteer clean-up efforts and coastal litter surveys have raised the public's awareness of marine debris as well as provided valuable data on the categories of litter items that are most abundant and/or frequently found on beaches and waterways [1,2]. In addition, microplastics have been shown to be ubiquitous in the open ocean [3,4]. In general, debris items fall into two broad categories: fishing-related gear such as lines, nets, and buoys; and end-use consumer items such as plastic bags, plastics bottles, metal and plastic bottle caps, cigarette butts, expanded polystyrene (EPS) containers and a variety of other food packaging items (ICC website [5]). The top 10 items collected during Ocean Conservancy's annual International Coastal Cleanup have remained remarkably consistent, with cigarette butts topping the list and plastic items making up 83% of the remaining items (ICC website [5]).

While identifying the types and amount of debris that are frequently found on beaches is an important first step, understanding the impacts of those consumer items is critical if effective voluntary or regulatory measures are to be implemented to limit their impacts. The number of scientific publications on marine debris has increased dramatically in the last ten years and nearly 700 marine species are now known interact with marine debris [6]. Entanglement and ingestion are the two main mechanisms by which marine taxa are exposed to marine debris ([7]; others) with contamination from toxic chemicals a secondary consequence of ingestion. At present, there is far less known about the toxicological impacts of marine litter but this is an active area of scientific enquiry and a growing conservation concern

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http://dx.doi.org/10.1016/j.marpol.2015.10.014
0308-597X/© 2016 Published by Elsevier Ltd.

([8,9,10], others). While individual cases of effects marine debris ingestion and entanglement have been reported for the last several decades [7], the population-level consequences of marine debris from ingestion, entanglement and contamination remains relatively unknown.

The population-level impact of debris to wildlife has been poorly quantified in part due to the difficulty of studying wildlife–debris interactions in the natural environment, and the potential bias of evaluating only a subset of the population represented by sick, injured or deceased animals found washed ashore ([11,12]; but see [13]). In particular, it is virtually impossible to undertake carefully controlled studies of debris impacts on wide ranging marine megafauna, including seabirds, turtles, and marine mammals, all of which are known to be affected at the individual level. This has limited our broad-scale understanding of the impacts of litter across marine taxa, particularly the relative potential impact that common debris items may have on the fitness of different taxa, including those with threatened or endangered status.

Although population scale field studies remain a challenge, there is substantial informal knowledge in the scientific community that could provide a preliminary basis for evaluating the impact of debris on marine megafauna. Elicitation techniques can be used to formalize this knowledge, providing preliminary estimates of the impact of marine debris on populations of marine megafauna. This analytical approach has been successfully applied to a range of issues including gaining an understanding of the potential impacts of climate change on seabirds (Wilcox et al., unpublished), identifying marine debris research priorities for the coming century [14], and prioritising the anthropogenic and environmental threats to sea turtles [15].

We present data from an elicitation survey asking about the impact of marine litter entanglement, ingestion and contamination on marine megafauna (seabirds, turtles and marine mammals). These data are used to estimate the proportion of each of the focal taxa affected and the impact on those individuals affected by each of the most common types of debris as identified from coastal clean-data from around the globe. These results are synthesised, controlling for expert bias, to provide bounded estimates on the population impacts from marine debris for each taxa and type of debris. This quantitative assessment can be used to prioritise interventions on those items with the greatest impacts due to ingestion, entanglement and chemical contamination.

2. Materials and methods

2.1. Survey instrument

An internet-based survey was carried out to quantify the ecological impact posed by the most persistent forms of coastal litter to three major marine taxa: seabirds, sea turtles, and marine mammals. The survey was specifically targeted to experts working on major marine taxa, individuals working on marine debris specifically, and/or those involved in or with an interest in the field. Items addressed in this survey have been identified as the most common items found during Ocean Conservancy's annual International Coastal Cleanup since 1989, and are broadly consistent with several studies that have documented the composition of debris in the marine environment [16-18]; (see Table S1 for the 20 marine debris items of interest for which information was elicited). Microplastics were included as a discrete debris type even though they arise from a variety of plastic products, given their ubiquity in the marine environment and concern over their impacts on marine taxa [19,20].

The survey was developed using the threat ranking systems implemented by the World Wildlife Fund's Threat Rank Classification, the International Union for Conservation of Nature (IUCN) and Bird Life International's World Bird Database. Respondents assigned scores with respect to severity (i.e. the outcome of an interaction with debris for an animal in the taxon) and specificity (i.e. the proportion of a total taxon expected to be affected by the debris interaction). The survey covered each taxon (bird, turtle and mammal) and each mode of debris impact (entanglement, ingestion, and chemical contamination). Respondents were provided with quantitative, but non-overlapping intervals for each score in a multiple-choice format (Table S2).

A preliminary version of the survey was developed, then trialled with a small number of experts to evaluate its clarity, ease of use, and targeting. Based on the responses, along with verbal feedback in focus groups, the survey was revised. The scope of the taxa and the breakpoints among the multiple choice categories were revised based on initial feedback, to balance ease of use and quality of the resulting data.

Respondents' expertise and professional experience working with each of the taxa covered by the survey was ascertained to evaluate any potential bias and account for it statistically (see Section 2.2 below; Table S3). The survey was distributed to four international list-servers on 30 April 2014 (with the survey accessible online until 31 May 2014). These list servers included marine debris, marine taxa (list servers that focused on seabird, sea turtle and marine mammals specifically), marine policy, and education list servers: MARMAM, IUCN-DCMC, International Coastal Cleanup Coordinators, Turtle, Scuttlebutt, and PacificSeabirdsGroup.

2.2. Statistical analyses

We first evaluated the significance of respondent identity in determining the scores for severity and specificity of each debris type. Models were compared using debris type, respondent ID, and both terms with a null model including only an intercept using Aikaie Information Criteria (AIC) [21].

For cases where respondent ID was an important predictor of the scored values for severity and specificity, a cumulative link mixed model with respondent ID as a random component of the intercept term was used, to remove any bias among the scores from each respondent. These models were implemented in the Ordinal package in the *R* statistical language [22].

Each of the three types of impacts; entanglement, ingestion, and contamination, was analysed separately. Using the fitted cumulative link models, the effect of the type of debris (of the 20 most common types) and the taxa (bird, sea turtle and mammal) in determining respondent scores for specificity and severity was estimated.

Once the scores were standardized across respondents, interval statistics were used to construct estimates of the population-level impact of each type of impact – taxa combination. This was done by using the joint lower bounds of the proportion of the taxa affected and the magnitude of the effect to estimate the minimum effect for each taxa. The joint upper bound of the proportion and magnitude was used to estimate a maximum effect in a similar manner.

3. Results

3.1. Survey respondents

Two hundred and seventy four people responded to the survey, with 31% completing all questions (see Table S3 or ⟨https://www.surveymonkey.com/s/CY8CRC8⟩ for the survey). Respondents who completed the entire survey represented 19 fields of study, with the majority of participants describing their work as conservation