

Deep Fishing: Dream or Disaster?

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Introduction

A great deal of emphasis has been placed on the need to be careful about human impact on the world's oceans. International attention is exemplified by targets established by the United Nations¹ in regard to issues such as pollution, marine protected areas, harvesting, and ocean acidification. Elements common to most of the expressed concerns include sustainability and the need to use the best available scientific information for guidance. There has been particular attention paid to harvesting resources at

depths greater than observed for most conventional fisheries (e.g., Norse et al., 2012; St. John et al., 2016). The mesopelagic zone (roughly 200–1,000 m in depth) is often characterized by a fish community including many species of Myctophiids (lanternfish) as well as other fish and invertebrates—often small-bodied species (e.g., krill, *Meganyctiphanes norvegica*). The overall complexity with which we are confronted in their evolutionary and ecological interactions is beyond conventional treatment (e.g., see: Merrie et al., 2018); the lack of holism in conventional approaches to management is pervasive.

St. John et al. (2016) cite previous work to indicate that there may be as much as 10 billion metric tons of biomass in mesopelagic communities that could potentially be harvested to help guarantee “sustainable development for our growing human population.” Without considering the lack of

sustainability for the observed human population, these authors are careful to emphasize the need to bring more holism to any decision. We whole-heartedly agree that holism is imperative, particularly when human participation in ecosystems and the biosphere is in question. We also agree that it is extremely important to bring the best available scientific information to the task—something conventional management fails to do (Fowler et al., 2013).

With this in mind, we take advantage of holistic normative information (Fowler, 2003, 2009; Fowler et al., 2013) to show that harvesting mesopelagic biomass, at depths where it is found, would be abnormal (and therefore unsustainable) for mammalian species of our body size. This deals with depth directly. As a large-scale environmental impact assessment, we extend this process by bringing holism, and the best available scientific

¹ E.g., see the 14 targets listed at <https://www.un.org/sustainabledevelopment/oceans/>.

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ABSTRACT—A team of European scientists recently raised concerns regarding the potential of harvesting biomass from mesopelagic ecosystems to help sustain the growing human population. They cite research showing that there may be up to 10 billion metric tons of pelagic biomass comprised of species in numerous taxonomic groups living at depths typically between 300 and 800 m—resources infrequently harvested commercially but with both benefits and risks to being harvested. They stressed the need for sustainable harvests, partly to avoid compromising the needs of future generations. They also stressed the need for further assessment, a more holistic understanding of the dynamics of deep-sea communities, and the need to consider the consequences of such harvests.

In this paper, we join this team of scientists in being precautionary—especially in bringing holism to decision making. We take

advantage of holistically normative natural patterns for guidance to avoid abnormal consequences of harvesting mesopelagic biomass—consequences involving systems such as other species, marine ecosystems, the marine environment, and the biosphere to include the sustainability of such systems themselves. This involves addressing questions such as “In comparison to other species, would harvesting mesopelagic resources involve abnormality in the depths at which humans harvest from the marine environment?” or “In comparison to other species, would harvesting mesopelagic resources contribute to abnormality in the total harvest currently taken by humans in the marine environment?” We consider other aspects of the human presence and influence on our planet and address observed abnormality as it would be influenced by mesopelagic harvests.

Our approach takes advantage of ho-

listic information important to any aspect of management, and especially harvesting resources. This is information about the participation in complex natural systems by other species. We begin by examining the abnormality that would be involved in taking resources at the depths where mesopelagic communities are observed to occur—to directly address the issue of depth. We then consider both directly and indirectly related dimensions of such harvesting to show how abnormality already observed in human participation in ecosystems and the biosphere would be accentuated. We conclude that it would be a serious mistake to harvest deep-sea resources. Harvesting at such depths would itself be an abnormality in the ways humans participate in marine ecosystems. It would also result in the accentuation or perpetuation of many other forms of abnormality—often already extreme in their magnitude.

information², to addressing questions related to other obvious consequences of harvesting mesopelagic biomass. An example of these questions is: “At what rate can we sustainably harvest biomass from the entire marine environment?”—owing to the fact that harvesting mesopelagic biomass would add to harvests that are already being taken from the marine environment. We take advantage of the interconnected nature of reality to carry this process forward to examine the sustainability of other dimensions of being a species involved in harvesting mesopelagic biomass (e.g., energy consumption, CO₂ production, and other direct and indirect consequences of harvesting biomass). Rather than seeking to sustain the human population, we acknowledge the abnormality of our population and strive to avoid perpetuation of management that makes this and associated problems worse (e.g., extinction rates associated with the effects of overpopulation (Gaston, 2005)).

Methods

In this paper, we drew upon the integrative (holistic, Fowler, 2009; Fowler et al., 2013) nature of information in naturally occurring patterns to assess the sustainability of harvesting resources from mesopelagic communities. The first question we addressed was “At what depths can we sustainably harvest marine resources?” A different way of expressing this question would be “At what depths can we harvest marine resources without engaging in abnormal participation in marine ecosystems?”

To address these questions, we used information that is consonant³ with the questions, that is, normative information regarding the depths at which marine mammals harvest resources as empirical examples of what works

² I.e., holistic information consonant³ with the questions being addressed (Fowler 2003; Fowler et al., 2013).

³ See Hobbs and Fowler (2008), Fowler (2009), Fowler et al. (2013), and Fowler and Hobbs (2011) for details regarding the concept of consonance.



Plate 1.—The spotted seal, *Phoca largha*, is a species that represents mammals of roughly human body size to serve as an example of ecological sustainability for humans to mimic (Photo: Dave Withrow, NOAA).

sustainably for mammals⁴—such species have been parts of natural systems for thousands of years and represent empirical examples of sustainability. The information we used was obtained by searching published literature regarding studies of the depths to which marine mammals dive in their foraging behavior. A list of such species was developed, accompanied by data regarding measures of the depths of their dives. Marine mammals are known for their sexual dimorphism; when depths were reported for both males and females of a particular species we used the mean to characterize the species. We recorded data, as available, for both the maximum depths to which dives were recorded as well as the mean depths associated with individual species.

Macroecological patterns often involve metrics that are related to body size (Peters, 1983⁵). In view of the possibility that such patterns include the depth to which mammals dive, it is important to account for body

⁴ We are mammals and using such information directly accounts for this taxonomic category for our species as one element of achieving consonance directly.

⁵ See also Roth (2014) and references therein.

mass directly in any patterns involving the depths at which resources are consumed/harvested. We humans, as a species, have a characteristic body size and this can be accounted for directly, in parallel to accounting directly for taxonomic category through comparing ourselves to mammals in regard to the depths at which we extract biomass. Thus, we also searched the literature, and online resources, for data regarding adult body size for the species of marine mammals represented by estimates of their respective depth of dives. As with data for depth, we used the mean of measurements for males and females to characterize adult body mass for individual species. To achieve consonance regarding size, we assumed that species in the range of one-half to twice the adult body mass of humans were approximately of human size; comparing ourselves (as a species) to large whales, for example, would not be a fair comparison. The refined management question (Hobbs and Fowler, 2008) becomes “At what depths can we, as a mammalian species with our characteristic body size, harvest marine resources without engaging in abnormal participation in marine ecosystems?”

Our treatment of measurements of other species-level characteristics that involve the consequences of harvesting mesopelagic biomass was based on previously published materials that reveal patterns consonant with the respective management questions.

Results

Figure 1 illustrates the relationship between maximum depth of dives and body size for 51 species of marine mammals (Appendix Table A1.1 contains the results of our compilation of data for depth of dives, and Appendix Table A2.1 contains data for body size). The mean of maximum diving depths is 442 m. The vertical dashes represent body sizes equivalent to half and double the mean adult body size assumed for humans (68 kg). Species characterized by body mass within this range are species with which we can compare our species and avoid the lack of consonance involved in comparing ourselves to species outside of this range.

Figure 2 depicts the frequency distribution of maximum diving depths for the 14 species represented in Figure 1 as species that have adult body sizes that are between half and twice that for humans (i.e., within the range that we have defined to be approximately of human body size).

Figure 3 shows the frequency distribution of Figure 2 in comparison to the depths of mesopelagic biomass identified by St. John et al. (2016), from the second panel of their Figure 2, showing the echogram for the Irminger Sea, as recorded in 2013. We note that the bulk of the biomass shown in this echogram is below the mean of maximum diving depths for marine mammals (235 m). Harvesting this biomass would be a matter of participating in ecosystems like this in ways that would result in measurable abnormality for mammals of our body size and should be avoided.

Figure 4 shows a pattern similar to that of Figure 1, here as measures of mean (rather than maximum) depth of dives, again plotted against estimates of mean adult body mass. As with Fig-

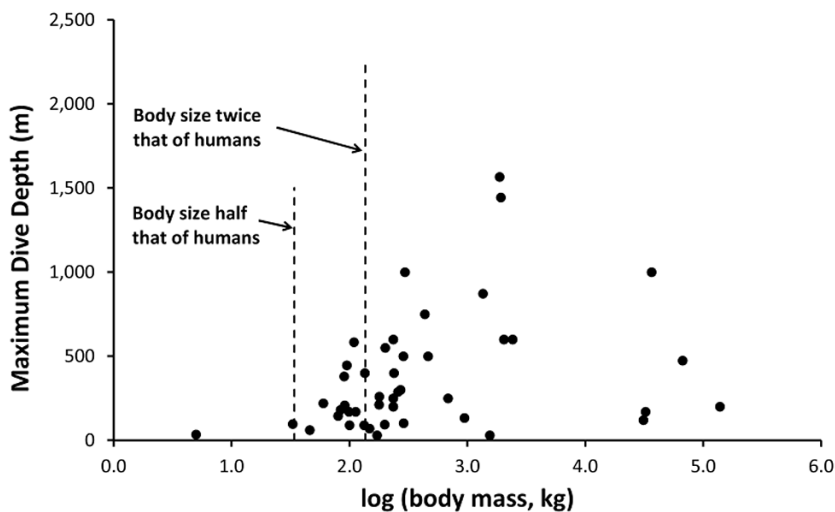


Figure 1.—Pattern among *maximum* diving depths observed for 51 species of marine mammals (Appendix Table A1.1), in relation to mean adult body size (Appendix Table A2.1).

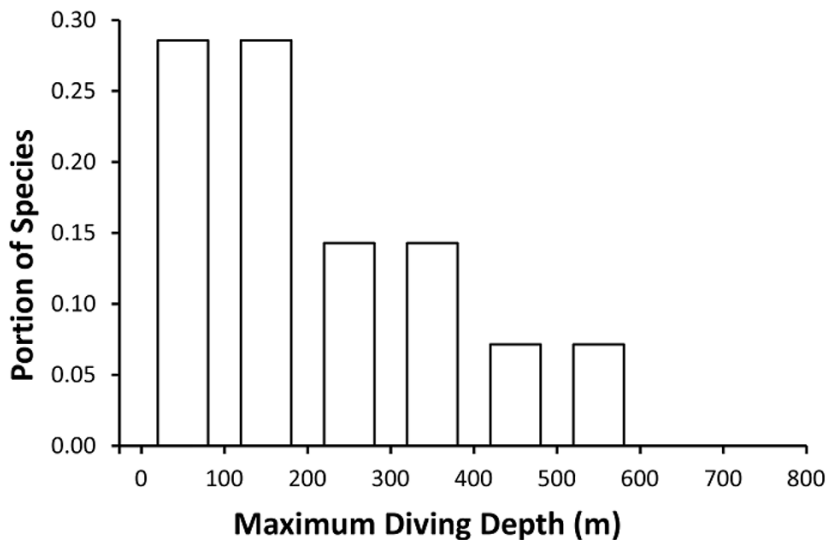


Figure 2.—Frequency distribution of maximum diving depths for the 14 species of marine mammals shown in Figure 1 with adult body sizes that are between half and twice the body size assumed for humans ($\bar{x} = 235$ m).

ure 1, the upper and lower bounds of mean adult body mass similar to that of humans are identified by the vertical dashed lines. The average mean depth of dives for species ($N = 12$) of roughly human body mass is 87 m.

Figure 5, otherwise similar to Figure 3, compares the frequency distribution

of mean diving depths for mammalian species of roughly human body mass to the depths of biomass observed in the mesopelagic community. Here the abnormality of harvesting at such depths is more obvious as nearly all of the observed mesopelagic biomass is below the 87 m average mean depth

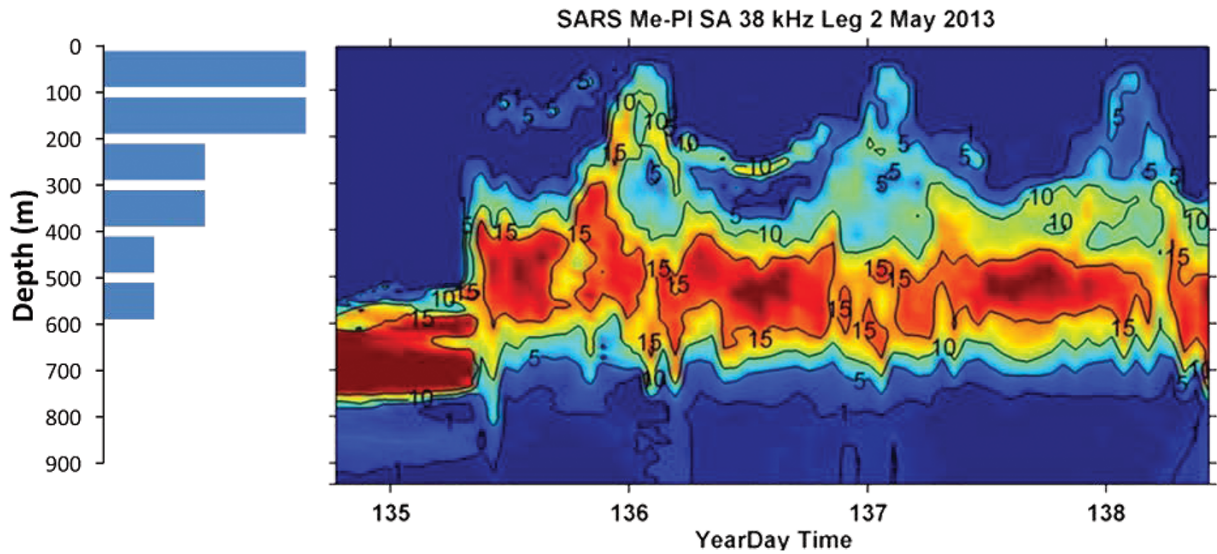


Figure 3.—Histogram of Figure 2 (blue bars in left panel) rotated 90° clockwise to show a comparison of maximum diving depths for marine mammals of approximately human body size with the depths at which mesopelagic biomass occurs (the darker red areas in the right panel show the highest densities of biomass – from Figure 2, page 2, of St. John et al., 2016).

of dives for the marine mammals with body sizes similar to ours. This, by itself, is evidence that harvesting mesopelagic biomass is to be avoided; it would be abnormal to harvest at such depths.

The depth at which harvests are taken involves only one dimension of harvesting marine resources and was the only issue addressed directly, specifically with the results presented above. Another factor of concern is that of the harvesting itself. We must deal with sustainability in the total biomass we humans harvest from the marine environment. This brings us to more management questions. One of primary and obvious relevance is “At what rate can humans sustainably harvest biomass from the marine environment?” (or “At what rate can we harvest marine resources to participate normally in the marine environment?”). Each can be refined to account for factors such as body size. Such questions are important because any harvest of mesopelagic biomass would add to the total of existing harvests of marine biomass by humans.

Figure 6 shows the abnormality of harvests of marine biomass by hu-

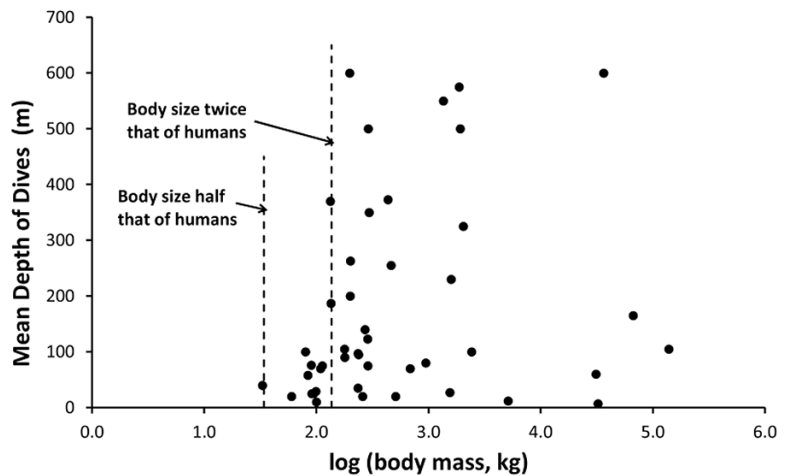


Figure 4.—Pattern of mean diving depths, as observed for 45 species of marine mammals, in relation to mean adult body size (as based on data from Appendix Tables A1.1 and A2.1).

mans in the late 1900s in comparison to that of 15 other species of mammals with body mass roughly similar to that of humans. In this graph, there are three components. The pie chart in part A is an illustration of the diversity of rates at which marine mammals of our body size are estimated to have consumed biomass from the world’s oceans. The

area of this chart is equivalent to that of the section of the chart in part B that represents the nonhuman species (with colors identical to those in part A); the total area of both charts is proportional to the total take in each case, with humans making up the red component of the larger chart. In part C, the abnormality apparent in part B is revealed in a histogram (with log

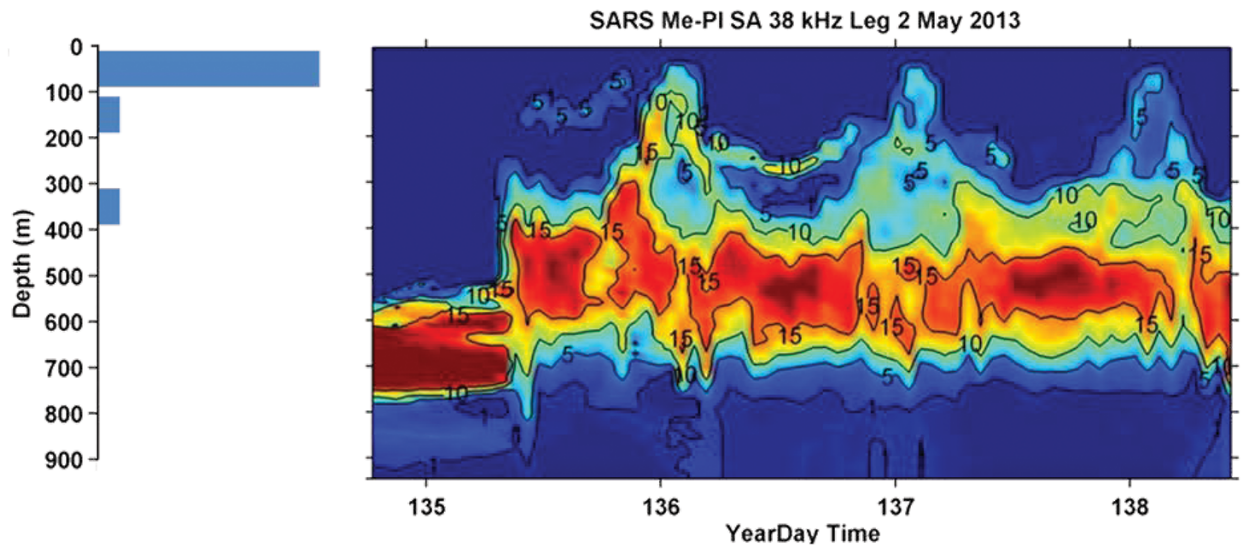


Figure 5.—Comparison of mean diving depths for 12 species of marine mammals of roughly human body mass to the depths of mesopelagic biomass (see Figure 3). (\bar{x} = 87 m for mean depth of dives).

transformation of the data used in the pie charts) revealing the harvest by humans to be an outlier. The harvest by humans was over 61-fold larger than the mean among the other species. Clearly, the biodiversity of this consumer/resource system is compromised by the dominance of humans. Maximizing the biodiversity of this system (following procedures described by Fowler (2008)) would have required reducing the harvest by more than 97%. Assuming that an abnormality of this magnitude is observed currently, adding a harvest of biomass from the mesopelagic resources identified by St. John et al. (2016) would obviously accentuate the inherent and related problem(s) and is, by itself, also basis for rejecting any proposal to harvest more mesopelagic biomass.

Marine protected areas are another facet of management in harvesting from the marine environment. Harvesting mesopelagic biomass would do nothing to reduce the area of the Earth's oceans that are subjected to harvests (one direct anthropogenic impact); it would likely result in an increase. This gives rise to the management question: "What portion of the marine environment should be areas in which harvesting is prohibited?"

For our purposes "What portion of the marine environment should be designated as areas in which fishing is not allowed so as to participate normally (sustainably) in oceanic systems in regard to marine protected areas?"

Figure 7 shows the results of addressing this question with empirical

data. We used data for estimated geographic range sizes for 102 species of marine mammals (as published by Pompa et al., 2011; see Appendix 3, Table A3.1). The mean percent of the world's oceans left unoccupied by the 40 species of roughly human body mass (again bounded by the two ver-



Plate 2.—The gray whale, *Eschrichtius robustus*, is a species that represents mammals but with a body size too large to be considered similar to humans; as a species, it does not necessarily serve well as an example of ecological sustainability for humans to mimic (Photo: C. W. Fowler).

Total Marine Biomass Consumed by 16 Species (1000 metric tons per year)

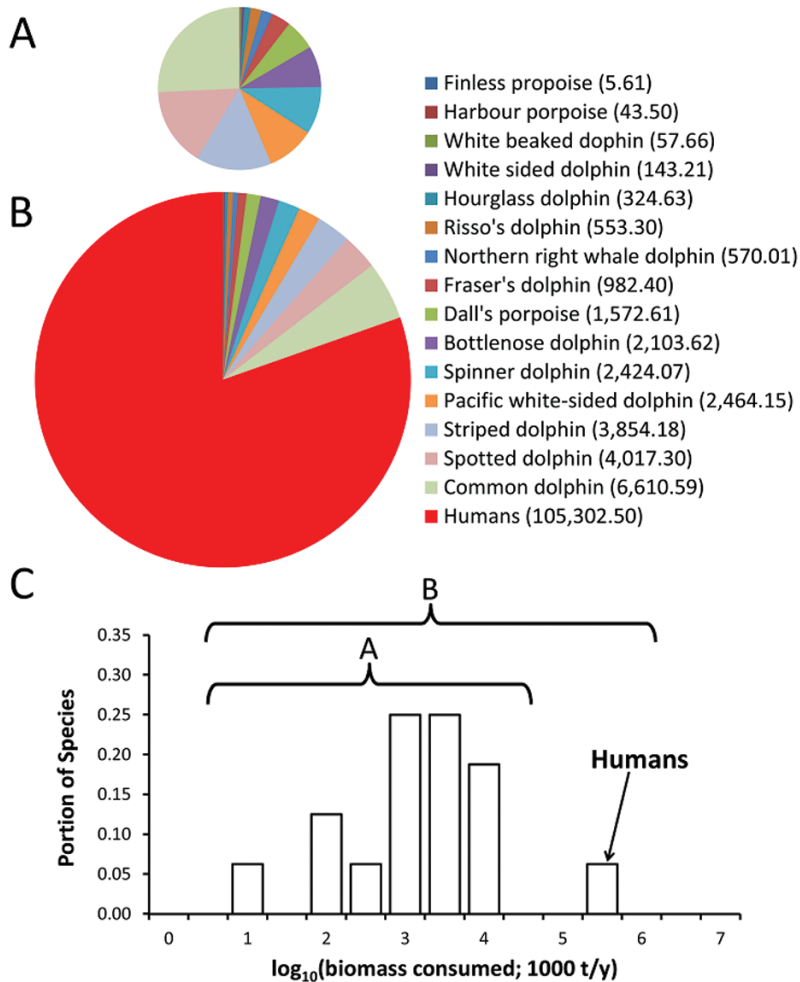


Figure 6.—Comparison of the total annual harvests of biomass from the marine environment by humans for the late 1900s compared to the pattern in consumption by 15 species of marine mammals similar in size to humans, based on data used by Fowler and McCluskey (2011).

tical dashed lines) is 98.7%, based on logit transformed data. Humans are undoubtedly already harvesting from more than 1.3% of the marine environment (see Appendix 3)⁶. Adding any additional area needed to harvest mesopelagic biomass would again accentuate an extreme human abnormal-

⁶ Jones et al. (2018) indicate that only 6.97% of the world's oceans are designated marine protected areas.

ity and be grounds for concluding that we should not harvest these resources.

Another consequence⁷ of harvesting mesopelagic biomass would be the consumption of energy. This would include energy needed to conduct the harvest, transport catches, process for consumption (either directly by hu-

⁷ Holistically, there may be an infinite set of such consequences.

mans or domestic species), delivery of resulting products to stores and homes, as well as the manufacture, maintenance, and disposal of the equipment involved. At what rate can the human species sustainably consume energy? How much energy can humans consume without being abnormal in our participation in the biosphere?

Figure 8 shows the pattern in global energy consumption by 64 species of mammals of roughly human body size (including humans). As in Figure 6, the area of the tiny pie chart at the top left (representing 63 nonhuman species) is the same as the miniscule wedge in the chart that includes humans. This chart is enlarged on the right so that the diversity in rates of consumption among the nonhuman species can be seen. Both the pie chart including humans and the histogram of log transformed data below illustrate the abnormality that would be accentuated by the additional energy consumption associated with taking and using biomass from the mesopelagic community. The consumption of energy by humans is already over 20,000 times greater than the mean rate of consumption by other species of roughly human body mass (Fowler, 2008). Harvesting mesopelagic biomass would escalate this abnormality; additional harvests from the marine environment of any kind are ill-advised.

Energy consumption, of course, often involves burning fossil fuels with emissions that include carbon dioxide. Comparison of CO₂ production by humans to that of other species (Fowler and Oppenheimer, 2017) results in observing abnormality very similar to that for total energy consumption (Fig. 8). As with all of the abnormalities treated above, removing biomass from mesopelagic communities would amplify the abnormality of anthropogenic CO₂ production and all of its consequences (including ocean acidification)—already orders of magnitude larger than normal for mammalian species of our body size (Fowler, 2008). Alone, but especially in combination with other abnormalities, accentuated atypical CO₂ production

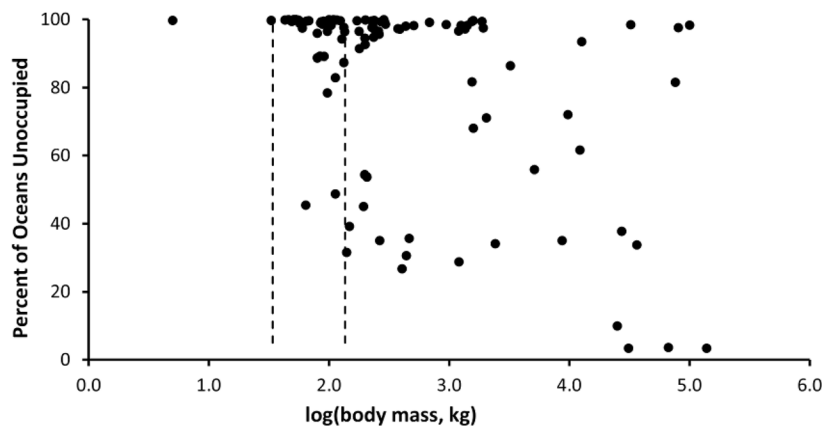


Figure 7.—Illustration of the pattern for the percent of the world’s oceans that are not occupied by 102 species of marine mammals as related to body mass (with dashed lines showing limits to the range of species of body sizes similar to that of humans as in Fig. 1 and 4). See text and Appendix 3 for details.

caused by harvesting mesopelagic biomass again leads to the conclusion that it is to be avoided.

Finally, St. John et al. (2016) recognize a connection between food consumption and the human population. Attempts to find resources to feed the human population require that we ask the question: “How large is a sustainable human population?” What human population would be of normal size in comparison to the populations of other mammals of our body size? Figure 9 displays the abnormality of our population; continuing to provide food to feed this population is another example of maintaining the status quo when it is not holistically sustainable. The human population is currently orders of magnitude larger than central tendencies among nonhuman species of mammals with body sizes similar to ours (Fowler, 2008, 2009), and providing more food would tend to induce further growth, ultimately magnifying this abnormality and its consequent problems. Maintaining abnormality in any of the ways we participate pathologically in nature is to be avoided; their consequences count among the problems observed globally. In particular, we conclude that the harvest of biomass from mesopelagic communities should be avoided.

Discussion

The results of our work involve only a very small sample of abnormalities in our species’ participation in the natural world, particularly in the marine environment. Harvesting biomass from the mesopelagic community would bring about innumerable forms

of additional influence on communities at depths that would be abnormal if done by any mammalian species of our body size. Thus, the depth that such harvesting would involve is, by itself, basis for rejecting any suggestion to harvest such biomass.⁸ Owing to the interconnected nature of reality, however, the list of related unsustainable (abnormal) participatory modes of human existence extends well beyond depth (Fig. 5) to include total marine biomass consumption (Fig. 6), portions of the Earth used for extracting resources (Appendix 3), global energy consumption (Fig. 8), CO₂ production, and population size (Fig. 9). Harvesting mesopelagic biomass would almost certainly accentuate them all, including those beyond the scope of this paper and involving the innumerable components of all systems that would be impacted—directly, indirectly, now or later.

Even among known examples of abnormality, the sample above is small. The numerous ways in which we ex-

⁸ A complete and distinct scientific paper could have focused on this issue alone.

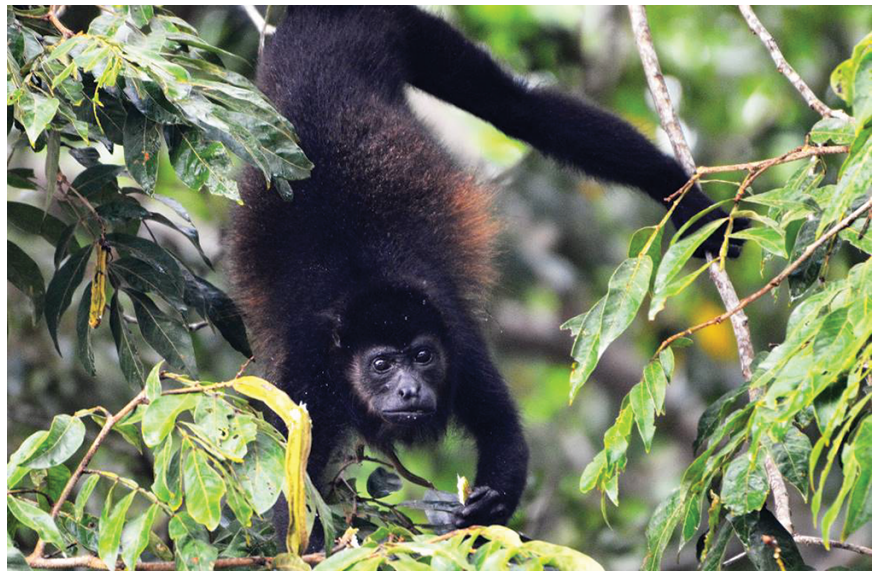


Plate 3.—The howler monkey, *Alouatta palliata*, is a species that represents mammals but with a body size too small to be considered similar to humans; as a species, it does not necessarily serve well as an example of ecological sustainability for humans to mimic (Photo: C. W. Fowler).

hibit abnormality (pathological participation or lack of sustainability) are seen in measures that often involve several orders of magnitude (Fowler and Hobbs, 2003; Fowler, 2008, 2009). Although fisheries management has resulted in confining abnormality in the rates of harvesting to about one or two orders of magnitude (Fig. 6, Fowler et al., 2013; Darimont et al., 2015), harvesting mesopelagic biomass would clearly accentuate these problems. Beyond the simple issue of harvest rates, it is important to recognize that existing fisheries already contribute to the abnormality of things like energy consumption, carbon dioxide production, and overpopulation. In other words, the abnormal fishing observed in total takes from the marine environment (Fig. 6) is, without adding to it, already contributing to other forms of abnormality for our species—abnormality that would be magnified by harvesting mesopelagic biomass.

The full collection of abnormalities associated with human overpopulation is important to realize. The examples illustrated above are no more than a small sample; any management to maintain the status quo retains all of the impacts involved. Most of these impacts will probably remain unknown to science, but include things like the human impact on water supplies and ecosystems such as rivers and lakes, some of which have been completely destroyed already. Water consumption by humans counts among the examples of abnormality that are measured in orders of magnitude (Fowler, 2008). The abnormality of our population size is expressed in many indirect effects, including extinction (e.g., McKee et al., 2013; even the risk of our own), global warming, ocean acidification, and pollution (all to the extent, and in the ways, that population is actually involved). Thus, arguments to the effect that we need to consider harvesting mesopelagic biomass to feed the human population is a matter of maintaining the status quo when what we observe is abnormal and, therefore, not sustainable—not for humans, not

Total Energy Consumed by 64 Species (joules per year)

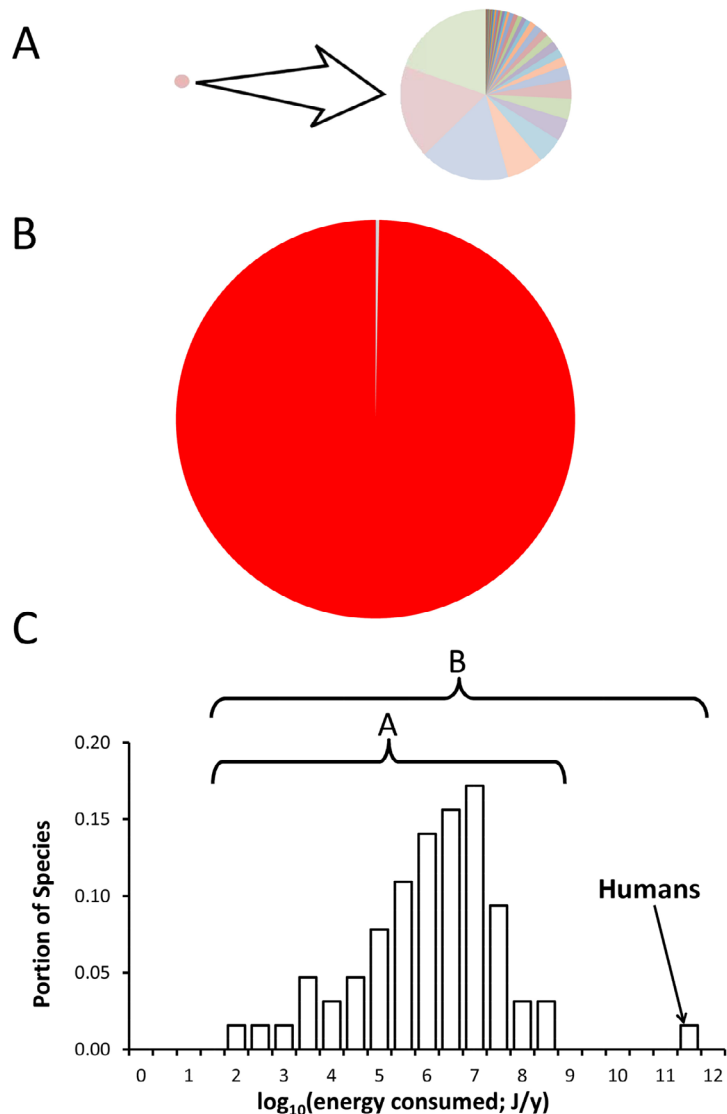


Figure 8.—Graphic representation of the pattern for annual energy consumption by 64 species of mammals of roughly human body mass illustrating the abnormality of consumption by humans (see Fowler, 2008).

for other species, not for their ecosystems, and not for the biosphere. These are all systems with which we interact and, for sustainability (both for theirs and ours), require sustainable interactions, participation, and consequences.

When faced with options like those

brought to our attention by St. John et al. (2016), we have the challenge of assessing environmental impacts holistically. From the perspective of the holistic approach we have brought to bear in this paper, any action we consider (any management decision) needs

Total Global Population for 64 Species

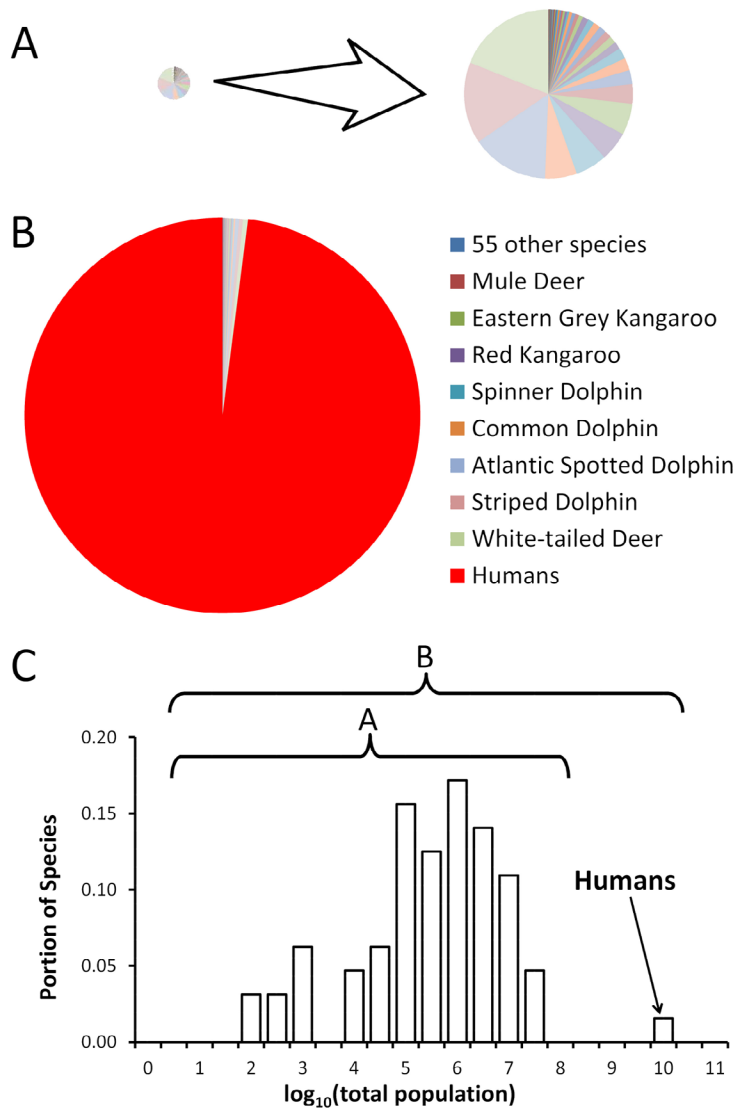


Figure 9.—Human population in comparison to the pattern for population size among 63 species of mammals of roughly human body mass (see Fowler, 2008).

to be treated consistently—consistency achieved by avoiding abnormality or ecologically pathological participation or interactions with the nonhuman. Cases of environmental impacts which would lead to prolonged or accentuated abnormality are cases for rejecting proposed management action. Holistically, this prevents factors such as human

greed, anthropocentrism, genetic predisposition, economics, politics, opinions, emotions, and values from driving us further into trouble by perpetuating or accentuating problems of the kinds already faced in today’s world.

Norse et al. (2012) provide conventional arguments against fishing from the deep sea. Their approach is

of the kind St. John et al. (2016) presumably had in mind in their advice to “guarantee a sustainable exploitation of these resources” to achieve more holism in the assessment and understanding of mesopelagic communities. The perspective behind our work involves the understanding that each identifiable component of such harvests can be dealt with in a completely holistic manner (Fowler, 2003, 2009; Fowler et al., 2013; Fowler et al., 2014); but we extend this to include larger management questions involving whether or not to take such a harvest at all. We hasten to emphasize, however, that a large part of the infinite set of management questions confronting our species remains beyond our grasp; only those management questions that we find it possible to ask can be addressed holistically (Hobbs and Fowler, 2008).

As such, we fully support St. John et al. (2016) in their advice to achieve holism in considering the potential of harvesting mesopelagic biomass. A great deal of holism is brought to the task in every way we can compare ourselves with other similar species (Hobbs and Fowler, 2008; Fowler, 2009; Fowler et al., 2013) and, through such comparisons, we find that human abnormality would be intensified in virtually all cases. The importance of avoiding ecologically pathological forms of impact on systems of which we are a part seems obvious. Otherwise, sustainability at all levels is compromised rather than achieved—including all temporal, spatial, and hierarchical scales. We conclude that it would be a serious mistake to harvest mesopelagic biomass owing to the perpetuation and accentuation of ways in which humans participate abnormally in the natural world and the consequential abnormality among other species, ecosystems, and the biosphere.

Summary

This paper is not only an example of an environmental impact statement at the global level; it also provides another example of using information consonant with management ques-



Plate 4.—The Delicate Arch (Arches National Park, U.S.) is found in a setting that reveals geological time scales as taken into account through the integrative holism of empirically observed phenomena (Fowler et al., 2013) exemplified by the normative patterns in this paper (Photo: C. W. Fowler).

tions—the best scientific information for guidance as well as evaluation. One aspect of the holism of such information involves its being applicable to any management question we are capable of asking. Our evaluation of the potential for harvesting biomass from mesopelagic communities (characterized by St. John et al., 2016) involves just one small set of examples wherein the application of such information is possible. However such information is applied, it involves a form of holism that is impossible in conventional approaches to decision making. Holism is made possible by the naturally integrative form of information embodied in patterns among species with which we can appropriately compare humans. In all of the ways we make such

comparisons, we find that harvesting mesopelagic biomass would aggravate anthropogenic abnormality.

The list of abnormalities for this case begins with the depths at which harvests would be taken. The set of pathological influences goes beyond this to include the area of oceans subjected to harvesting, total global marine harvest rates, consumption of energy, production of carbon dioxide, and overpopulation. The higher-order consequences of these forms of pathological impact are to be avoided. They are not sustainable for any of the living systems involved. We conclude that the dream of harvesting mesopelagic biomass would be a disaster; it is imperative that we reverse (rather than extend) our tendency to either main-

tain or accentuate pathological existence in the natural world.

Acknowledgments

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Appendix 1

Depth of Dive Information for Marine Mammals

Appendix Table A1.1 shows a list of marine mammal species (following nomenclature used by Pompa et al., 2011) for which we found information regarding the depths to which these species have been observed to dive. As for data regarding body mass (Appendix 2), we used the mean of measures of diving depths for any species with data from multiple sources; this often involved combinations of data for both sexes. As can be seen, a large portion of our data was obtained from the second edition of the Encyclopedia of Marine Mammals (Perrin et al., 2009). From this source, many sets of valuable data were found in the accounts for individual species by various specialists; however a significant portion of the data we used came from Stewart's (2009) account dealing directly with diving behavior.

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Table A1.1.—List of species of marine mammals for which there is information on the depths to which they dive while foraging, showing information for both the mean depths to which they dive and the maximum depths to which they have been observed to dive.

Species	Mean depth of dive (m)	Max. dive depth (m)	Sources
<i>Arctocephalus australis</i>	29	170	Campagna (2008)
<i>Arctocephalus forsteri</i>	76	380	Campagna (2008); Perrin et al. (2009)
<i>Arctocephalus galapagoensis</i>		61	Perrin et al. (2009)
<i>Arctocephalus gazelle</i>	58	181	Perrin et al. (2009)
<i>Arctocephalus philippii</i>	10	90	Perrin et al. (2009)
<i>Arctocephalus pusillus</i>	75	102	Perrin et al. (2009)
<i>Arctocephalus tropicalis</i>	25	208	Perrin et al. (2009)
<i>Balaenoptera musculus</i>	105	200	Perrin et al. (2009)
<i>Balaenoptera physalus</i>	165	474	Perrin et al. (2009)
<i>Callorhinus ursinus</i>	187	400	Perrin et al. (2009)
<i>Cystophora cristata</i>	350	1,000	Perrin et al. (2009)
<i>Delphinapterus leucas</i>	550	872	Perrin et al. (2009)
<i>Delphinus capensis</i>		200	Perrin et al. (2009)
<i>Delphinus delphis</i>	90	260	Perrin et al. (2009)
<i>Dugong dugon</i>		20	Perrin et al. (2009)
<i>Enhydra lutris</i>	40	97	Estes (1980)
<i>Erignathus barbatus</i>	20	288	Perrin et al. (2009)
<i>Eschrichtius robustus</i>	7	170	Perrin et al. (2009)
<i>Eumetopias jubatus</i>	70	250	Perrin et al. (2009); Merrick et al. (1994)
<i>Globicephala macrorhynchus</i>	100	600	Perrin et al. (2009)
<i>Globicephala melas</i>	325	600	Perrin et al. (2009)
<i>Halichoerus grypus</i>	140	300	Perrin et al. (2009)
<i>Lagenodelphis hosei</i>		600	Perrin et al. (2009)
<i>Leptonychotes weddellii</i>	373	750	Perrin et al. (2009)
<i>Lobodon carcinophaga</i>	35	600	Perrin et al. (2009); Hückstädt (2015)
<i>Lontra felina</i>		35	Larivière (1998)
<i>Megaptera novaeangliae</i>	60	120	Perrin et al. (2009)
<i>Mirounga angustirostris</i>	575	1,567	Perrin et al. (2009)
<i>Mirounga leonine</i>	500	1,444	Perrin et al. (2009)
<i>Monachus monachus</i>		500	Perrin et al. (2009)
<i>Neomonachus schauinslandi</i>	263	550	Perrin et al. (2009)
<i>Neophoca cinerea</i>		30	Perrin et al. (2009)
<i>Odobenus rosmarus</i>	80	133	Perrin et al. (2009)
<i>Ommatophoca rossii</i>	105	212	Perrin et al. (2009)
<i>Orcinus orca</i>		12	Perrin et al. (2009)
<i>Otaria byronia</i>	97	250	Perrin et al. (2009)
<i>Pagophilus groenlandicus</i>	370	90	Perrin et al. (2009)
<i>Phoca vitulina</i>	26	446	Perrin et al. (2009)
<i>Phocartos hookeri</i>	123	500	Perrin et al. (2009)
<i>Phocoena phocoena</i>	20	220	Perrin et al. (2009)
<i>Phocoenoides dalli</i>		94	Perrin et al. (2009)
<i>Physeter macrocephalus</i>	600	1,000	Perrin et al. (2009)
<i>Pseudorca crassidens</i>		230	Perrin et al. (2009)
<i>Pusa hispida</i>	100	145	Perrin et al. (2009)
<i>Stenella attenuate</i>	75	170	Perrin et al. (2009)
<i>Steno bredanensis</i>		70	Perrin et al. (2009)
<i>Trichechus manatus</i>	27	30	Perrin et al. (2009)
<i>Tursiops aduncus</i>		200	Perrin et al. (2009)
<i>Tursiops truncatus</i>	255	500	Perrin et al. (2009)
<i>Zalophus californianus</i>	95	400	Aurioles-Gamboa et al. (2015)
<i>Zalophus wollebaeki</i>	70	584	Trillmich (2015)
<i>Ziphius cavirostris</i>		1,888	Perrin et al. (2009)

Appendix 2

Adult Body Mass Estimates for Marine Mammals

Table A2.1 contains a list of 102 species of marine mammals with nomenclature used by Pompa et al. (2011) in their treatment of conservation as related to range size (See Appendix 3). This set of species was selected based in the availability of data for adult body mass. The purpose of this appendix is to document these data and their sources along with the methods we used in deriving the values contained in this table (estimates that were used in both our consideration of diving depths (Appendix 1) and unoccupied portions of various areas of the Earth (Appendix 3)). As can be seen in this table, the bulk of the data for body mass involved information from Perrin et al. (2009), Fowler and Perez (1999), Clauset (2013), and a website maintained by NOAA's National Marine Fisheries Service (<https://www.fisheries.noaa.gov/find-species>). Sources from Perrin et al. (2009) usually involved species-specific accounts authored by specialists familiar with the species listed.

Marine mammals are known for their sexual dimorphism. To the best of our ability, we used data that are reflective of the mean among males and

females. When ranges were reported for either sex, we chose the midpoint.

When there were data from more than one source, we used the mean. In cases where we found data for body size from three or more sources, we removed estimates (13 cases) that resulted in a range larger than half of the original mean; in some cases the data rejected involved what appeared to be estimates that were too large, and in other cases measurements that appeared to be too small. For example, the estimate from Fowler and Perez (1999) for *Sousa chinensis* was 85 kg. This was rejected in light of two other estimates that were very similar to each other (265 from Perrin et al. (2009) and 257 from Clauset (2013)) and, for this species, Fowler and Perez (1999) was not included in the sources list.

In all cases, we are mindful of variance related to factors such as the definition of adult status, sample size, geographic variability, and human error. Also, information from the sources we have used can easily have been based on the same original research. Clearly, there are imperfections that need to be addressed in future research and we emphatically support continued efforts to supply reliable estimates of adult body mass for as many species as possible.

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Table A2.1.—List of species from Pompa, et al. (2011) for which information regarding body mass was found in the literature.

Species	Body mass (kg)	log(body mass, kg)	Sources
<i>Arctocephalus australis</i>	99	1.996	Campagna (2008); Fowler and Perez (1999)
<i>Arctocephalus forsteri</i>	90	1.954	Campagna (2008); Fowler and Perez (1999)
<i>Arctocephalus galapagoensis</i>	46	1.663	Fowler and Perez (1999); Perrin et al. (2009)
<i>Arctocephalus gazella</i>	84	1.924	Fowler and Perez (1999); Perrin et al. (2009)
<i>Arctocephalus philippii</i>	100	2.000	Fowler and Perez (1999); Perrin et al. (2009); NMFS
<i>Arctocephalus pusillus</i>	288	2.459	Fowler and Perez (1999); Perrin et al. (2009)
<i>Arctocephalus townsendi</i>	101	2.004	Perrin et al. (2009); NMFS
<i>Arctocephalus tropicalis</i>	91	1.959	Fowler and Perez (1999); Perrin et al. (2009)
<i>Balaena mysticetus</i>	80,669	4.907	Fowler and Perez (1999); NMFS; Jefferson et al. (1993); Clauset (2013)
<i>Balaenoptera acutorostrata</i>	12,234	4.088	Fowler and Perez (1999); Jefferson et al. (1993); Clauset (2013)
<i>Balaenoptera bonaerensis</i>	8,709	3.940	Fujise et al. (1993); Lockyer (1976)
<i>Balaenoptera borealis</i>	25,000	4.398	Fowler and Perez (1999); Perrin et al. (2009); Clauset (2013)
<i>Balaenoptera edeni</i>	27,228	4.435	Fowler and Perez (1999); NMFS; Jefferson et al. (1993); Clauset (2013)
<i>Balaenoptera musculus</i>	138,573	5.142	Fowler and Perez (1999); Perrin et al. (2009); Clauset (2013)
<i>Balaenoptera physalus</i>	66,761	4.825	Fowler and Perez (1999); Perrin et al. (2009); NMFS; Clauset (2013)
<i>Berardius arnuxii</i>	9,733	3.988	Fowler and Perez (1999); Jefferson et al. (1993); Clauset (2013)
<i>Berardius bairdii</i>	12,647	4.102	Fowler and Perez (1999); Jefferson et al. (1993); Clauset (2013)
<i>Callorhinus ursinus</i>	135	2.130	Fowler and Perez (1999); Perrin et al. (2009)
<i>Caperea marginata</i>	3,227	3.509	Fowler and Perez (1999); Jefferson et al. (1993); Clauset (2013)
<i>Cephalorhynchus commersonii</i>	65	1.813	Fowler and Perez (1999); Jefferson et al. (1993); Clauset (2013)
<i>Cephalorhynchus eutropia</i>	55	1.740	Fowler and Perez (1999); Jefferson et al. (1993); Clauset (2013)
<i>Cephalorhynchus heavisidii</i>	56	1.748	Fowler and Perez (1999); Jefferson et al. (1993); Clauset (2013)
<i>Cephalorhynchus hectori</i>	51	1.708	Fowler and Perez (1999); Jefferson et al. (1993); Clauset (2013)
<i>Cystophora cristata</i>	295	2.470	Fowler and Perez (1999); Perrin et al. (2009); NMFS
<i>Delphinapterus leucas</i>	1,355	3.132	Fowler and Perez (1999); Perrin et al. (2009); NMFS; Clauset (2013)

Table Continued

Table A2.1.—Continued.

pecies	Body mass (kg)	log(body mass, kg)	Sources
<i>Delphinus capensis</i>	235	2.371	Perrin et al. (2009)
<i>Delphinus delphis</i>	179	2.253	Perrin et al. (2009); NMFS; Clauset (2013)
<i>Dugong dugon</i>	508	2.706	Fowler and Perez (1999); Jefferson et al. (1993)
<i>Enhydra lutris</i>	33	1.519	Fowler and Perez (1999); Estes (1980)
<i>Erignathus barbatus</i>	258	2.412	Fowler and Perez (1999); Perrin et al. (2009); NMFS
<i>Eschrichtius robustus</i>	32,417	4.511	Perrin et al. (2009); NMFS; Clauset (2013)
<i>Eubalaena australis</i>	76,110	4.881	Jefferson et al. (1993); Clauset (2013)
<i>Eubalaena japonica</i>	100,000	5.000	Perrin et al. (2009)
<i>Eumetopias jubatus</i>	686	2.836	Fowler and Perez (1999); Perrin et al. (2009)
<i>Feresa attenuata</i>	194	2.288	Fowler and Perez (1999); Jefferson et al. (1993); Clauset (2013)
<i>Globicephala macrorhynchus</i>	2,416	3.383	Fowler and Perez (1999); NMFS; Jefferson et al. (1993); Clauset (2013)
<i>Globicephala melas</i>	2,039	3.309	Fowler and Perez (1999); Jefferson et al. (1993); Clauset (2013)
<i>Grampus griseus</i>	405	2.607	Fowler and Perez (1999); NMFS; Jefferson et al. (1993); Clauset (2013)
<i>Halichoerus grypus</i>	271	2.433	Fowler and Perez (1999); Perrin et al. (2009); NMFS
<i>Histiophoca fasciata</i>	85	1.929	Perrin et al. (2009); NMFS
<i>Hydrurga leptonyx</i>	374	2.573	Fowler and Perez (1999); Perrin et al. (2009)
<i>Kogia breviceps</i>	440	2.643	Fowler and Perez (1999); Perrin et al. (2009); NMFS; Clauset (2013)
<i>Kogia sima</i>	264	2.422	Fowler and Perez (1999); Perrin et al. (2009); NMFS; Clauset (2013)
<i>Lagenodelphis hosei</i>	198	2.297	Perrin et al. (2009); NMFS; Clauset (2013)
<i>Lagenorhynchus acutus</i>	228	2.358	Fowler and Perez (1999); Perrin et al. (2009); NMFS; Clauset (2013)
<i>Lagenorhynchus albirostris</i>	237	2.375	Fowler and Perez (1999); Perrin et al. (2009); NMFS; Clauset (2013)
<i>Lagenorhynchus australis</i>	116	2.064	Fowler and Perez (1999); Perrin et al. (2009); Clauset (2013)
<i>Lagenorhynchus cruciger</i>	113	2.053	Fowler and Perez (1999); Perrin et al. (2009); Clauset (2013)
<i>Lagenorhynchus obliquidens</i>	128	2.107	Fowler and Perez (1999); Perrin et al. (2009); NMFS; Clauset (2013)
<i>Lagenorhynchus obscurus</i>	104	2.017	Fowler and Perez (1999); Perrin et al. (2009); Clauset (2013)
<i>Leptonychotes weddellii</i>	435	2.638	Fowler and Perez (1999); Perrin et al. (2009)
<i>Lissodelphis borealis</i>	97	1.987	Fowler and Perez (1999); Perrin et al. (2009); NMFS; Clauset (2013)
<i>Lissodelphis peronii</i>	97	1.987	Fowler and Perez (1999); Perrin et al. (2009); Clauset (2013)
<i>Lobodon carcinophaga</i>	235	2.371	Fowler and Perez (1999);
<i>Lontra felina</i>	5	0.699	Larivière (1998)
<i>Megaptera novaeangliae</i>	31,084	4.493	Fowler and Perez (1999); Jefferson et al. (1993); Clauset (2013)
<i>Mesoplodon carlhubbsi</i>	1,584	3.200	Jefferson et al. (1993); Clauset (2013)
<i>Mesoplodon densirostris</i>	1,208	3.082	NMFS; Jefferson et al. (1993); Clauset (2013)
<i>Mesoplodon europaeus</i>	1,200	3.079	NMFS; Jefferson et al. (1993)
<i>Mesoplodon grayi</i>	1,550	3.190	Jefferson et al. (1993); Clauset (2013)
<i>Mesoplodon mirus</i>	1,414	3.150	NMFS; Jefferson et al. (1993); Clauset (2013)
<i>Mirounga angustirostris</i>	1,875	3.273	Fowler and Perez (1999); Perrin et al. (2009)
<i>Mirounga leonina</i>	1,920	3.283	Fowler and Perez (1999); Perrin et al. (2009)
<i>Monachus monachus</i>	290	2.462	Fowler and Perez (1999); Perrin et al. (2009); NMFS
<i>Monodon monoceros</i>	1,256	3.099	Fowler and Perez (1999); Perrin et al. (2009); Clauset (2013)
<i>Neomonachus schauinslandi</i>	201	2.303	Fowler and Perez (1999); Perrin et al. (2009); NMFS
<i>Neophoca cinerea</i>	171	2.233	Fowler and Perez (1999); Perrin et al. (2009)
<i>Neophocaena phocaenoides</i>	57	1.756	Fowler and Perez (1999); Perrin et al. (2009); Clauset (2013)
<i>Odobenus rosmarus</i>	944	2.975	Fowler and Perez (1999); Perrin et al. (2009)
<i>Ommatophoca rossii</i>	178	2.250	Fowler and Perez (1999); Perrin et al. (2009)
<i>Orcaella heinsohni</i>	124	2.093	Perrin et al. (2009)
<i>Orcinus orca</i>	5,115	3.709	Fowler and Perez (1999); Perrin et al. (2009); Clauset (2013)
<i>Otaria byronia</i>	235	2.371	Fowler and Perez (1999); Hückstädt (2015)
<i>Pagophilus groenlandicus</i>	133	2.124	Perrin et al. (2009); NMFS
<i>Peponocephala electra</i>	207	2.316	Fowler and Perez (1999); Perrin et al. (2009); NMFS; Clauset (2013)
<i>Phoca largha</i>	88	1.944	Fowler and Perez (1999); NMFS
<i>Phoca vitulina</i>	95	1.978	Fowler and Perez (1999); Perrin et al. (2009); NMFS
<i>Phocartos hookeri</i>	286	2.456	Fowler and Perez (1999); Perrin et al. (2009)
<i>Phocoena dioptrica</i>	86	1.934	Fowler and Perez (1999); Perrin et al. (2009)
<i>Phocoena phocoena</i>	60	1.778	Fowler and Perez (1999); Perrin et al. (2009); NMFS; Clauset (2013)
<i>Phocoena sinus</i>	53	1.724	Fowler and Perez (1999); NMFS; Jefferson et al. (1993); Clauset (2013)
<i>Phocoena spinipinnis</i>	68	1.833	Fowler and Perez (1999); Perrin et al. (2009); Clauset (2013)
<i>Phocoenoides dalli</i>	199	2.299	Perrin et al. (2009); NMFS; Clauset (2013)
<i>Physeter macrocephalus</i>	36,433	4.561	Fowler and Perez (1999); Perrin et al. (2009); Clauset (2013)
<i>Pontoporia blainvillei</i>	43	1.633	Perrin et al. (2009); Clauset (2013)
<i>Pseudorca crassidens</i>	1,587	3.201	Fowler and Perez (1999); Clauset (2013)
<i>Pusa hispida</i>	80	1.903	Perrin et al. (2009); NMFS
<i>Sotalia fluviatilis</i>	49	1.690	Perrin et al. (2009); Clauset (2013)
<i>Sousa chinensis</i>	261	2.417	Perrin et al. (2009); Clauset (2013)
<i>Sousa teuszii</i>	228	2.358	Perrin et al. (2009); Clauset (2013)
<i>Stenella attenuata</i>	113	2.053	Fowler and Perez (1999); Perrin et al. (2009); NMFS; Clauset (2013)
<i>Stenella clymene</i>	80	1.903	NMFS; Jefferson et al. (1993); Clauset (2013)
<i>Stenella coeruleoalba</i>	140	2.146	Fowler and Perez (1999); Perrin et al. (2009); NMFS; Clauset (2013)
<i>Stenella frontalis</i>	133	2.124	Perrin et al. (2009); NMFS; Clauset (2013)
<i>Stenella longirostris</i>	64	1.806	Fowler and Perez (1999); Perrin et al. (2009); NMFS; Clauset (2013)
<i>Steno bredanensis</i>	148	2.170	Fowler and Perez (1999); Perrin et al. (2009); NMFS; Clauset (2013)
<i>Trichechus manatus</i>	1,550	3.190	Fowler and Perez (1999); Perrin et al. (2009)
<i>Tursiops aduncus</i>	200	2.301	Perrin et al. (2009)
<i>Tursiops truncatus</i>	464	2.667	NMFS; Jefferson et al. (1993); Clauset (2013)
<i>Ursus maritimus</i>	388	2.589	Perrin et al. (2009)
<i>Zalophus californianus</i>	238	2.377	Fowler and Perez (1999); NMFS; Aurioles-Gamboa et al. (2015)
<i>Zalophus wollebaeki</i>	109	2.037	Perrin et al. (2009)

Appendix 3

Comparing Humans to Other Species in Regard to Geographic Range Size and Portions of Ecosystems Left Unoccupied

Figure A3.1 shows the data from Table A3.1 regarding geographic range size in relationship to body size (for species common to both Tables A2.1 and A3.1). As can be seen, there is a tendency for geographic ranges of smaller species (roughly similar to humans) to be smaller, on average, than those of larger species (\bar{x} = 21,840,963 vs. 87,643,257 km², respectively). This, and the larger variance among smaller species, is similar to what is observed among other taxa, including terrestrial mammals (e.g., Brown and Maurer, 1989; Diniz-Filho and Tôres, 2002).

Figure 7 (in the main text) is based on calculations of the portion of the Earth's oceans not occupied by the species of marine mammals for which Pompa, et al. (2011) estimated geographic range sizes. These unoccupied areas (areas outside the geographic range of each species) are areas wherein there is no consumption of resources (being mindful of the potential that resources from these areas may migrate, or be carried by currents, to areas within the geographic ranges of the species listed). The unoccupied areas are the equivalent of marine protected areas for each species and are thus informative as empirical examples of holistically sustainable marine protected area.

In the calculations behind the data of Table A3.1, the total area of these oceans was assumed to be 361,900,000 km² and the area not occupied by each species was calculated by subtracting the geographic range size of each species. This was then divided by the total area to get the portion left free of the direct influence of consumption (data consonant with the management question involving sustainable portions of the full marine environment to set aside in protected status). Further information regarding the specifics of our methodology can be found in Fowler and Johnson (2015).

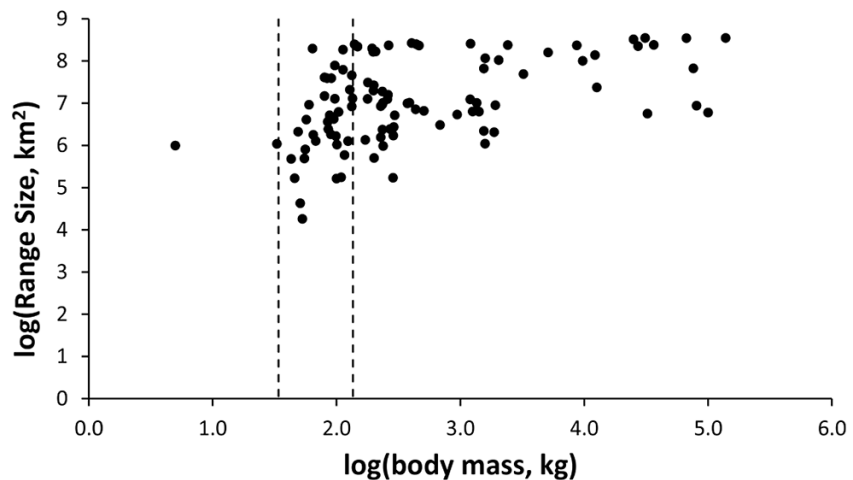


Figure A3.1.—Pattern in geographic range size, as related to body size, for 102 species of marine mammals listed in Table A3.1 for which there are data for body mass (Table A1.1). As in text Figure 1, the dashed lines are the upper and lower bounds of species with body sizes roughly similar to that of humans.

Table A3.1.—Geographic range size for 116 species of marine mammals (from Pompa et al., 2011) showing the percent of the marine environment occupied, and the portion unoccupied, based on 361,900,000 km² as a measure of the area of the world's oceans.

Species	Range size (km ²)	% of oceans occupied	Portion of oceans unoccupied
<i>Arctocephalus australis</i>	1,674,290	0.46	0.9954
<i>Arctocephalus forsteri</i>	1,823,240	0.50	0.9950
<i>Arctocephalus galapagoensis</i>	167,512	0.05	0.9995
<i>Arctocephalus gazella</i>	39,155,300	10.82	0.8918
<i>Arctocephalus philippii</i>	163,932	0.05	0.9995
<i>Arctocephalus pusillus</i>	1,705,430	0.47	0.9953
<i>Arctocephalus townsendi</i>	1,045,950	0.29	0.9971
<i>Arctocephalus tropicalis</i>	39,249,100	10.85	0.8915
<i>Balaena mysticetus</i>	8,735,490	2.41	0.9759
<i>Balaenoptera acutorostrata</i>	138,899,000	38.38	0.6162
<i>Balaenoptera bonaerensis</i>	235,109,000	64.97	0.3503
<i>Balaenoptera borealis</i>	325,876,000	90.05	0.0995
<i>Balaenoptera edeni</i>	225,248,000	62.24	0.3776
<i>Balaenoptera musculus</i>	349,620,000	96.61	0.0339
<i>Balaenoptera physalus</i>	348,861,000	96.40	0.0360
<i>Berardius arnuxii</i>	101,075,000	27.93	0.7207
<i>Berardius bairdii</i>	23,620,500	6.53	0.9347
<i>Callorhinus ursinus</i>	12,935,900	3.57	0.9643
<i>Caperea marginata</i>	49,073,400	13.56	0.8644
<i>Cephalorhynchus commersonii</i>	1,780,950	0.49	0.9951
<i>Cephalorhynchus eutropia</i>	493,046	0.14	0.9986
<i>Cephalorhynchus heavisidii</i>	802,273	0.22	0.9978
<i>Cephalorhynchus hectori</i>	42,555	0.01	0.9999
<i>Cystophora cristata</i>	5,167,870	1.43	0.9857
<i>Delphinapterus leucas</i>	10,167,800	2.81	0.9719
<i>Delphinus capensis</i>	9,313,700	2.57	0.9743
<i>Delphinus delphis</i>	31,026,900	8.57	0.9143
<i>Dugong dugon</i>	6,586,460	1.82	0.9818
<i>Enhydra lutris</i>	1,084,750	0.30	0.9970
<i>Erignathus barbatus</i>	12,550,800	3.47	0.9653
<i>Eschrichtius robustus</i>	5,640,160	1.56	0.9844
<i>Eubalaena australis</i>	66,669,400	18.42	0.8158
<i>Eubalaena japonica</i>	5,995,590	1.66	0.9834
<i>Eumetopias jubatus</i>	3,051,310	0.84	0.9916
<i>Feresa attenuata</i>	198,729,000	54.91	0.4509
<i>Globicephala macrorhynchus</i>	238,501,000	65.90	0.3410
<i>Globicephala melas</i>	104,690,000	28.93	0.7107
<i>Grampus griseus</i>	265,158,000	73.27	0.2673
<i>Halichoerus grypus</i>	2,443,290	0.68	0.9932
<i>Histiophoca fasciata</i>	3,625,450	1.00	0.9900
<i>Hydrurga leptonyx</i>	9,900,130	2.74	0.9726
<i>Hyperoodon ampullatus</i>	12,598,000	3.48	0.9652
<i>Hyperoodon planifrons</i>	86,815,900	23.99	0.7601
<i>Indopacetus pacificus</i>	106,594,000	29.45	0.7055
<i>Kogia breviceps</i>	251,271,000	69.43	0.3057
<i>Kogia sima</i>	235,194,000	64.99	0.3501

Table Continued

It is important to note that any area on the surface of the Earth can be taken as an ecosystem. As seen in Figure A3.2, the portion of ecosystems that would be set aside for sustainable protection increases with their size when using the means among species otherwise similar to humans as holistic guidance. As can be seen in Figure A3.3, the portion of the world's oceans used for fishing leaves much less than 93.8% in protected status (the arithmetic mean among species of approximately human body mass, compared to the mean of logit transformed data reported earlier) and additional harvesting to extract mesopelagic biomass would most likely accentuate this abnormality. The portion set aside in marine protected status as a matter of management is miniscule compared to the mean the areas left unoccupied by other species of mammals of our body size).

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Table A3.1.—Continued.

Species	Range size (km ²)	% of oceans occupied	Portion of oceans unoccupied
<i>Lagenodelphis hosei</i>	165,128,000	45.63	0.5437
<i>Lagenorhynchus acutus</i>	8,519,550	2.35	0.9765
<i>Lagenorhynchus albirostris</i>	10,168,600	2.81	0.9719
<i>Lagenorhynchus australis</i>	590,641	0.16	0.9984
<i>Lagenorhynchus cruciger</i>	61,848,200	17.09	0.8291
<i>Lagenorhynchus obliquoides</i>	20,853,700	5.76	0.9424
<i>Lagenorhynchus obscurus</i>	6,186,320	1.71	0.9829
<i>Leptonychotes weddellii</i>	7,146,790	1.97	0.9803
<i>Lissodelphis borealis</i>	12,737,400	3.52	0.9648
<i>Lissodelphis peronii</i>	78,075,800	21.57	0.7843
<i>Lobodon carcinophaga</i>	18,961,100	5.24	0.9476
<i>Lontra felina</i>	996,197	0.28	0.9972
<i>Megaptera novaeangliae</i>	349,580,000	96.60	0.0340
<i>Mesoplodon bidens</i>	13,884,300	3.84	0.9616
<i>Mesoplodon bowdoini</i>	4,419,570	1.22	0.9878
<i>Mesoplodon carlhubbsi</i>	1,096,570	0.30	0.9970
<i>Mesoplodon densirostris</i>	257,754,000	71.22	0.2878
<i>Mesoplodon europaeus</i>	12,338,600	3.41	0.9659
<i>Mesoplodon ginkgodens</i>	3,486,050	0.96	0.9904
<i>Mesoplodon grayi</i>	66,140,000	18.28	0.8172
<i>Mesoplodon hectori</i>	5,066,070	1.40	0.9860
<i>Mesoplodon layardii</i>	83,734,500	23.14	0.7686
<i>Mesoplodon mirus</i>	6,300,090	1.74	0.9826
<i>Mesoplodon perrini</i>	8,015,760	2.21	0.9779
<i>Mesoplodon peruvianus</i>	12,321,700	3.40	0.9660
<i>Mesoplodon stejnegeri</i>	6,809,010	1.88	0.9812
<i>Mirounga angustirostris</i>	2,054,680	0.57	0.9943
<i>Mirounga leonina</i>	8,976,400	2.48	0.9752
<i>Monachus monachus</i>	2,730,360	0.75	0.9925
<i>Monachus schauinslandi</i>	503,740	0.14	0.9986
<i>Monodon monoceros</i>	6,370,340	1.76	0.9824
<i>Neophoca cinerea</i>	1,347,900	0.37	0.9963
<i>Neophocaena phocaenoides</i>	4,086,040	1.13	0.9887
<i>Odobenus rosmarus</i>	5,367,060	1.48	0.9852
<i>Ommatophoca rossii</i>	12,649,700	3.50	0.9650
<i>Orcaella brevirostris</i>	4,252,570	1.18	0.9882
<i>Orcaella heinsohni</i>	1,264,170	0.35	0.9965
<i>Orcinus orca</i>	159,671,000	44.12	0.5588
<i>Otaria flavescens</i>	2,371,930	0.66	0.9934
<i>Pagophilus groenlandicus</i>	8,352,950	2.31	0.9769
<i>Peponocephala electra</i>	167,492,000	46.28	0.5372
<i>Phoca largha</i>	5,173,220	1.43	0.9857
<i>Phoca vitulina</i>	4,233,030	1.17	0.9883
<i>Phocarcotus hookeri</i>	171,500	0.05	0.9995
<i>Phocoena dioptrica</i>	2,431,640	0.67	0.9933
<i>Phocoena phocoena</i>	9,201,080	2.54	0.9746
<i>Phocoena sinus</i>	18,196	0.01	0.9999
<i>Phocoena spinipinnis</i>	1,274,860	0.35	0.9965
<i>Phocoenoides dalli</i>	19,888,000	5.50	0.9450
<i>Physefer macrocephalus</i>	239,682,000	66.23	0.3377
<i>Pontoporia blainvillei</i>	480,376	0.13	0.9987
<i>Pseudorca crassidens</i>	115,652,000	31.96	0.6804
<i>Pusa hispida</i>	14,792,000	4.09	0.9591
<i>Sotalia fluviatilis</i>	2,115,420	0.58	0.9942
<i>Sousa chinensis</i>	15,839,700	4.38	0.9562
<i>Sousa teuszii</i>	1,554,490	0.43	0.9957
<i>Stenella attenuata</i>	185,346,000	51.21	0.4879
<i>Stenella clymene</i>	40,843,500	11.29	0.8871
<i>Stenella coeruleoalba</i>	247,740,000	68.46	0.3154
<i>Stenella frontalis</i>	45,684,100	12.62	0.8738
<i>Stenella longirostris</i>	197,320,000	54.52	0.4548
<i>Steno bredanensis</i>	220,032,000	60.80	0.3920
<i>Tasmacetus shepherdi</i>	4,419,310	1.22	0.9878
<i>Trichechus manatus</i>	2,189,720	0.61	0.9939
<i>Tursiops aduncus</i>	26,634,700	7.36	0.9264
<i>Tursiops truncatus</i>	232,786,000	64.32	0.3568
<i>Ursus maritimus</i>	10,273,300	2.84	0.9716
<i>Zalophus californianus</i>	966,957	0.27	0.9973

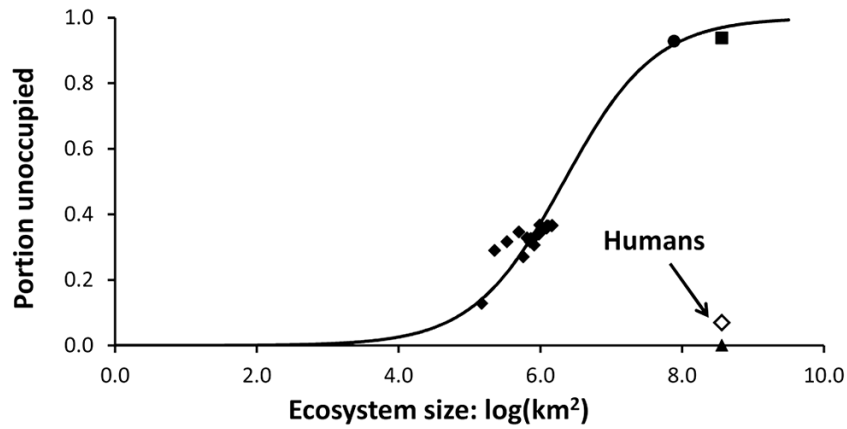


Figure A3.2.—Pattern in mean portion of marine environments left unoccupied by marine mammals, as related to the area being considered. The diamonds to the lower left represent data for 21 species treated by Fowler and Johnson (2015), with the geographic range of each species within the eastern Bering Sea as a distinct ecosystem. The dot to the upper right is for the mean area outside the geographic ranges of the same 21 species expressed as a portion of the entire North Pacific. The square to the upper right represents the mean of unoccupied portions of entire marine environment for species of human body size from Pompa et al. (2011). The symbols at the lower right illustrate the area set aside in protected status by humans (triangle: IUCN: <http://www.protectplanetoccean.org/collections/introduction/introbox/globalmpas/introduction-item.html>; diamond: Jones et al. (2018)). The curved line assumes upper and lower limits of 1.0 and 0.0.

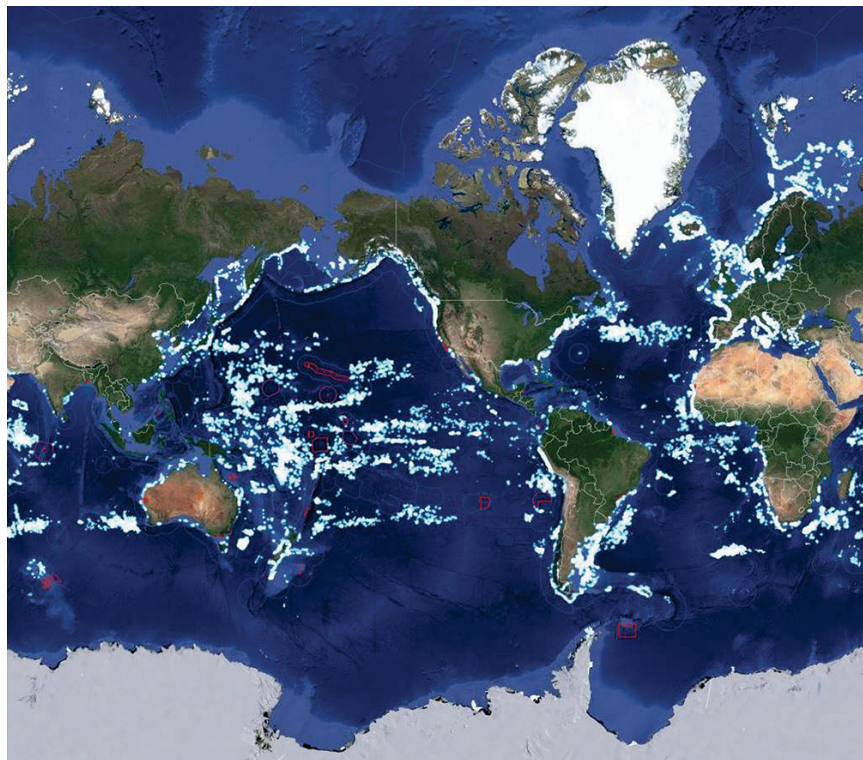


Figure A3.3.—Distribution of fishing activity around the globe from 31 Dec. 2011 to 31 May 2017 based on information displayed at <http://globalfishingwatch.org/map/>.