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Climate change and the cetacean community of north-west Scotland

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Abstract

1. Climate change is thought to affect the composition and structure of local ecological communities. We investigate whether ocean warming around north-west Scotland since 1981 has been associated with changes in the local cetacean community.

2. Analysis of strandings from 1948 to 2003 found that no new species per decade were recorded in north-west Scotland between 1965 and 1981. This rose to 2.0 new species per decade from 1988 onwards. The new species recorded since 1988 are generally restricted to warmer waters, while those recorded prior to 1981 regularly occur in colder waters.

3. In the period 1992 to 2003, the relative frequency of stranding of white-beaked dolphin, a colder water species, has declined while strandings of common dolphin, a warmer water species, have increased. Similarly, sightings surveys conducted in May–September 2002 and 2003 show that the relative occurrence and abundance of white-beaked dolphins have declined and common dolphins increased in comparison to previous studies.

4. These observations are consistent with changes in the local cetacean community being driven by increases in local water temperature. If such temperature changes continue, some formerly abundant cold-water species, such as white-beaked dolphins, may be lost from this cetacean community. In a wider context, such changes may lead to populations of cetaceans moving out of areas specifically designated for their protection as they respond to changes in local oceanic conditions.

Keywords: Climate change; Cetacean communities; Cetacean conservation

1. Introduction

Climate change is thought to affect the composition and structure of ecological communities (Lemoine and Boehning-Gaese, 2003; Genner et al., 2004). As local conditions change, new species may join communities while others may disappear from them or change in their relative and absolute abundances (Lemoine and Boehning-Gaese, 2003; Bush et al., 2004; Genner et al., 2004). Such changes, particularly in megafauna, can, in turn, lead to changes in species diversity, patterns of energy flow and, in the most extreme cases, alterations to entire ecosystems (Jackson and Sala, 2001).

Here, we investigate whether recent oceanic climate change has been sufficient to alter a local cetacean community and what implications this may have for the conservation of cetaceans. The composition of the cetacean community of north-west Scotland (Fig. 1) was examined for evidence of changes over time and changes identified were compared to changes in local ocean climate to investigate whether the two could be linked. This cetacean community was investigated for three reasons:

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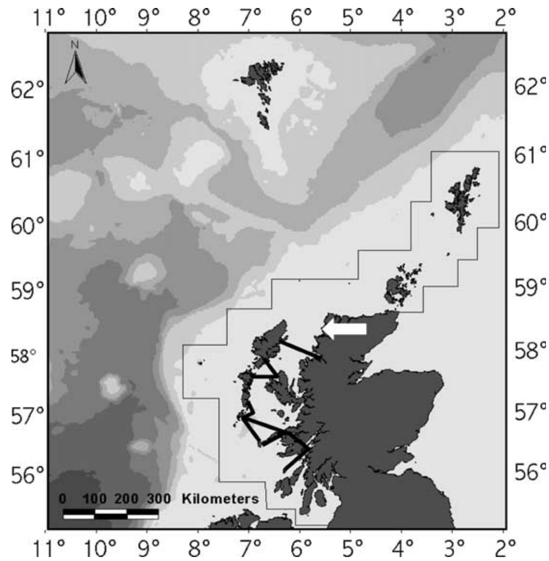


Fig. 1. The study area covering north-west Scotland used to investigate changes in cetacean community. This study area included all western and northern coasts of the Scottish mainland as well as all western and northern isles. Back ground shading: Water depths separated by 200, 500, 1000, 1500, 2000 and 2500 m contours. White Arrow: position of monitoring site (Handa Island) where cetacean presence was recorded between 1987 and 1991. Black Lines: Transect lines repeatedly covered by systematic surveys during summer months in 2002 and 2003 using passenger ferries as platforms of opportunity. Latitudes are degrees north, longitudes are degrees west.

1. Since 1981 there has been a documented increase of 0.2–0.4 °C per decade in local sea water temperatures (Fisheries Research Service, 2003);
2. Good time-series data are available on species presence through a long-term systematic strandings record (Fraser, 1974; Sheldrick, 1989; Sheldrick et al., 1994; SAC, Unpublished data);
3. A number of studies have examined cetacean occurrence and relative abundance in this area over the last two and a half decades (Evans, 1980; Evans, 1992; Pollock et al., 2000).

If recent changes in water temperature have led to changes within this cetacean community, we predict that as temperatures have increased, new species with ranges restricted to warmer waters will have been recorded in the area. Secondly, we predict that the abundance of species with a preference for colder water temperatures will have decreased, while species with preferences for warmer waters will have increased.

2. Methods

Changes in the cetacean community of north-west Scotland were investigated in two ways. Firstly, the composition of the community as represented by stranded animals was examined. We compared systematically collected strandings records over a 55 year period between 1948 and 2003 (Fraser, 1974; Sheldrick, 1989; Sheldrick et al., 1994; Reid et al., 1993; Bones et al., 1998; SAC, Unpublished data.) This range was selected as it includes the period of known temperature increase (1981 onwards) as well as the preceding 33 years, allowing a baseline of cetacean presence to be established prior to the period of known temperature change. Unless is was specifically stated that species identification of a stranding was questionable, it was assumed that the reported species identification was correct. However, if the identification of a stranded animal was subsequently corrected, the updated identification was used for this analysis.

These strandings records were used to generate an accumulation curve starting at zero species recorded at the start of 1948, with each species being added based on its year of first record. If the community composition has remained constant, such an accumulation curve would be expected to reach an asymptote after a certain period of time representing the recording of almost all possible species within the community. For this to prove useful for the current analysis, this asymptote should be reached prior to the main period of interest (1981 onwards). Such an accumulation curve would then act as a baseline to investigate whether the local ocean warming has led to the addition of warm water species to the local cetacean community as this would result in an increase in the slope of the accumulation curve above this asymptote.

However, strandings effort is likely to have varied between each year. In particular, since 1992 there has been a dedicated strandings investigation programme, leading to an increase in the number of recorded strandings events. Therefore, to investigate whether the first record of each species was simply a function of effort, a Monte Carlo simulation was conducted to test the null hypothesis that there has been no change in strandings patterns since 1948.

The total number of strandings events for each species recorded between 1948 and 2003 was calculated. The underlying trend in effort in recording stranding events was modelled using a generalised additive model (GAM) with Poisson distribution log-link function and four degrees of freedom. This modelled trend was then used to weight the probability of a simulated stranding event occurring in any one year. Thus, the probability of each stranding event occurring in any one year was calculated using a weighted randomised procedure, with each stranding event for each species assigned at random to a year using the year-specific all species combined weighting derived from the GAM. From the resulting randomised dataset, an accumulation curve could be derived based on the year each species first occurred. This procedure was repeated 1000 times to estimate the most likely accumulation curve assuming that there has been no change in the composition of the local cetacean community between 1948 and 2003. In addition, the median expected year of first occurrence for each species within the strandings record was identified. The difference between the expected and the actual accumulation curve, and the median expected and actual first record for species that first stranded after 1981 were then examined.

Secondly, we investigated changes in the occurrence of two widespread and regionally abundant cetacean species: The common dolphin, *Delphinus delphis*, and the white-beaked dolphin, *Lagenorhynchus albirostris*. The common dolphin is found throughout the warmer waters of the world, while the white-beaked dolphin is restricted to the colder waters of the North Atlantic. North-west Scotland is close to both the northern limit of the common dolphin and the southern limit of the white-beaked dolphin in the eastern North Atlantic. Both these dolphin species are relatively easy to identify, are similar in body length, commonly occur in coastal areas, consume similar prey and have similar reactions to vessels. Therefore, they provide a suitable comparative pairing to investigate relative changes in the occurrence of a warm and a cold water species in the study area.

Changes in the patterns of occurrence of these species were investigated in two ways. Firstly, the relative proportions of strandings of the two species were compared from 1992 to 2003, the period covered by the dedicated strandings programme. The frequency of stranding of each species in each half of this period (1992–1997 and 1998–2003) was compared using a Chi-squared test with Yates' correction for one degree of freedom. The expected values were calculated from the total number of strandings per six year period by multiplying it by the total number of strandings per species and dividing by the total number of strandings 1992–2003. As the relative difference in strandings frequency was examined, differences in the level of reporting of strandings between the two time periods could not account for any significant differences between the two species. To place any changes in these two species in the context of the cetacean community as a whole, a Monte Carlo simulation was used to examine whether (a) the the frequency of strandings of each species within the most recent six years and (b) the year of first occurrence of each species in the historical record were consistent with predictions for a simulated fixed community composition over the whole time period from 1948 to 2003, taking into account underlying changes in observer effort by using total observed strandings (across all species) as an effort index.

Changes in the occurrence of white-beaked and common dolphins were further investigated by comparing sightings frequencies and relative abundances of these two species from previous studies (Evans, 1980; Evans, 1992; Pollock et al., 2000) to new data collected in 2002 and 2003. The new data were collected by means of repeated surveys along eight transects, using passenger ferries as research platforms, between May and September (Fig. 1). Surveys were conducted by a single observer positioned on one side of the vessel, providing a view from approximately 20° to starboard through to 135° to port. Scans of this field of view were conducted continuously using 7x50 reticulated binoculars and the naked eye. When a group of cetaceans was sighted, they were identified to the lowest taxonomic level of certainty (e.g., common dolphin, dolphin spp. or cetacean spp.) and the position, group size and composition were recorded. On return to shore, the position of each sighting, along with the distance surveyed were calculated using a geographic information system (GIS) constructed using ESRI Arcview software. The total distance surveyed in sea states of Beaufort 3 or less, along with the number of sightings and number of animals for each species, was calculated.

3. Results

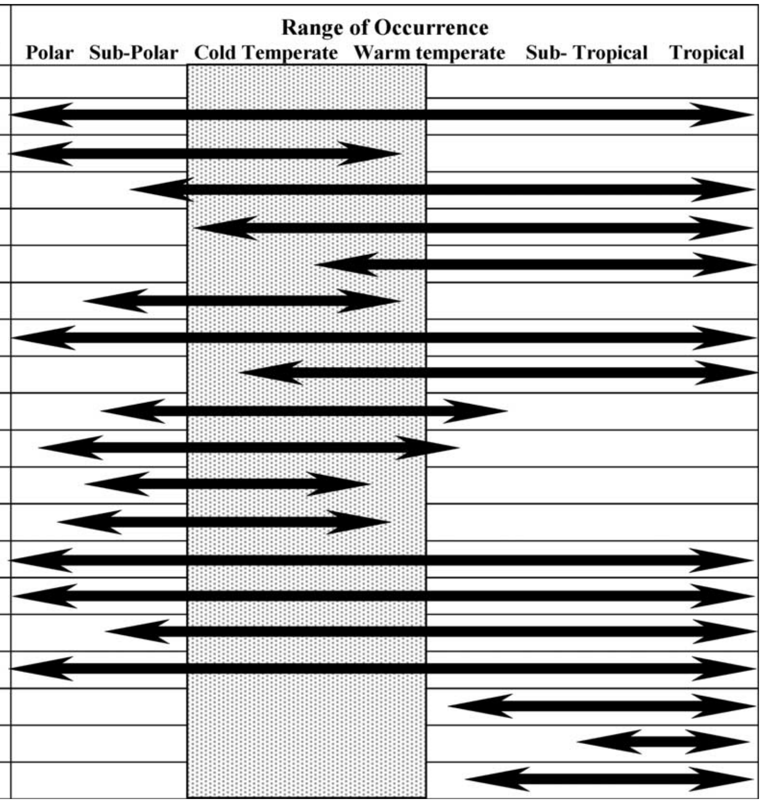
Nineteen species of cetaceans were recorded stranding in north-west Scotland between 1948 and 2003 (Table 1). Fifteen of these species were recorded between 1948 and 1981. In this time period, the species accumulation curve is consistent with a stable, unchanging community, with a rapid increase in the number of new species recorded in the first few years (13.5 species per decade from 1948 to 1963) followed by a long period where no new species were recorded (0 species per decade from 1965 to 1981 – Fig. 2).

After 1981, the first new species recorded was the humpback whale (*Megaptera novaeangliae*), a very rare species in the north east Atlantic but one that regularly occurs in the waters around Scotland (Stevick et al., 2003). However, since 1988 the rate of accumulation of new species has increased to 2.0 species per decade, with three new species being recorded in the study area (Table 1; Fig. 2). All the species recorded between 1948 and 1988 have distributional ranges including areas of colder waters. In contrast, all three new species recorded since 1988 have ranges that are restricted to warmer waters (Table 1).

In the case of the simulated discovery curves ($n = 1000$), based on the assumption of an unchanging cetacean community against a background of increasing observer effort, a median of 10 species was recorded by 1955 (observed = 12; difference non-significant, $p = 0.067$), 13 species by 1965 (observed = 15; $p = 0.035$) and 3 new species since 1988 (observed = 3; $p = 0.230$). Thus there was a small but significant difference between the observed and simulated curves, consistent with the observed cetacean community having changed over the course of the studied period.

Table 1
Species recorded stranding in Scotland between 1948 and 2003 (from Fraser, 1974; Sheldrick, 1989; Sheldrick et al., 1994; Reid et al., 1993; Bones et al., 1998; SAC Unpublished data), with details of the year they were first recorded, their range of occurrences in terms of water temperatures

Species	First Record
Minke Whale	1948
Northern Bottlenose Whale	1948
Bottlenose Dolphin	1949
Risso's Dolphin	1949
Cuvier's Beaked Whale	1949
Sowerby's Beaked Whale	1949
Fin Whale	1949
Common Dolphin	1950
Long-Finned Pilot Whale	1950
Harbour Porpoise	1951
White-Sided Dolphin	1952
White-Beaked Dolphin	1953
Sperm Whale	1955
Killer Whale	1963
Sei Whale	1965
Humpback Whale	1985
Striped Dolphin	1988
Fraser's Dolphin	1996
Pygmy Sperm Whale	1999



Shaded area represents usual range of temperatures of waters around north-west Scotland through out the year.

For most species, the year of first appearance in the strandings record is consistent with the overall number of strandings recorded during the study period. There were two exceptions. Firstly, the fin whale first appeared in the strandings record much earlier than expected. However, this is based on a single record. More strikingly, the striped dolphin first appeared in the record in 1988. In the simulations ($n = 1000$ runs), the latest it appeared was 1979 (median year of first appearance 1953) and based on the total number of strandings events between 1948 and 2003 for this species, there was a very low probability ($p < 0.001$) of the species going unrecorded until 1988 if it had been present in the cetacean community throughout the study period.

There was a significant difference in the frequency of strandings of common and white-beaked dolphins in the first and second half of the time period between 1992 and 2003 ($X^2 = 10.3$, d.f. = 1, $p = 0.0013$). White-beaked dolphins stranded less frequently in the second half and common dolphins more frequently. In comparison to the community as a whole, the common dolphin is one of only three species that have significantly increased in stranding rate in the most recent six year period in comparison to the rates expected from the simulation. The other species are the striped dolphin and the harbour porpoise, *Phocoena phocoena* (Table 2). Thus, two of the three species that have significantly increased their strandings rate are restricted to warmer waters (Table 1). In contrast, four other species have significantly decreased in stranding rate in the same period. These are the killer whale, *Orcinus orca*, the long-finned pilot whale, *Globicephala melas*, Sowerby's beaked whale, *Mesoplodon bidens*, and the northern bottlenose whale, *Hyperoodon ampullatus* (Table 2). All these species are either restricted to colder waters (Table 1) or, in the case of the killer whale, less abundant in warmer waters (Dahlheim and Heyning, 1999).

During summer months of 2002 and 2003, 7053 km of survey effort were conducted. With 16 groups sighted, common dolphins were by far the most frequently encountered dolphin species. In comparison, only one group of white-beaked dolphins was recorded. The relative abundances of these two species were 0.019 and 0.00043 individuals per kilometre respectively.

Opportunistic sightings between 1973 and 1980 recorded many more sightings of white-beaked than

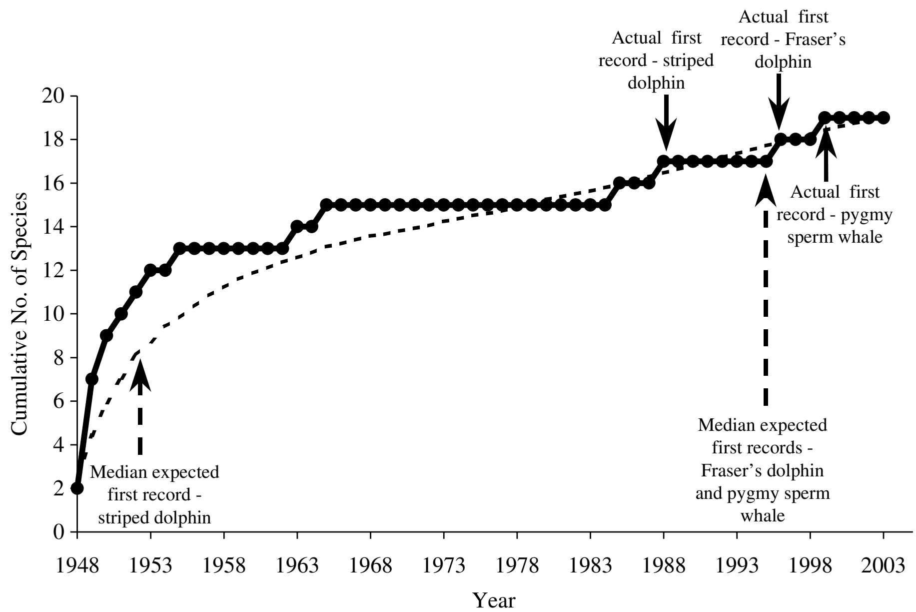


Fig. 2. Expected and actual accumulation curve of species diversity in north-west Scotland constructed from standings records between 1948 and 2003: solid line – actual accumulation curve for species; dashed line – expected accumulation curve based on 1000 Monte Carlo simulations and assuming random stranding of species across years corrected for changes in reporting of strandings and the relative frequency of stranding events for each species; solid arrows – actual first year of occurrence for three warm water species first recorded in north-west Scotland since 1988; dashed arrows – median expected first year of occurrence for these warm species in 1000 Monte Carlo simulations.

Table 2
Probability that observed changes in the frequency of stranding events for each species in north-west Scotland in the last six years have occurred by chance based on a 1000 Monte Carlo simulations corrected for changes in the level of effort and species specific strandings rates between 1948 and 2003

Species	Probability of as many strandings events 1998–2003 occurring by chance	Probability of as few strandings events 1998–2003 occurring by chance	Range of occurrence
Minke Whale	0.489	0.602	Tropical–polar
Bottlenose Dolphin	0.742	0.472	Tropical–sub polar
Risso's Dolphin	0.642	0.456	Tropical–cold temperate
Cuvier's beaked Whale	0.977	0.093	Tropical–warm temperate
Sowerby's beaked Whale	0.998	**0.006**	Warm temperate–sub polar
Fin Whale	0.905	0.372	Tropical–polar
Common Dolphin	**0.015**	0.991	Tropical–cold temperate
Long-finned Pilot Whale	0.997	**0.008**	Warm temperate-sub-polar
Harbour Porpoise	**0.005**	0.998	Warm temperate–polar
White-sided Dolphin	0.139	0.905	Cold temperate–sub-polar
White-beaked Dolphin	0.975	**0.035**	Cold temperate–sub-polar
Sperm Whale	0.966	0.056	Tropical–polar
Northern Bottlenose Whale	0.994	**0.023**	Cold temperate–sub-polar
Killer Whale	1.000	**0.000**	Tropical–polar
Sei Whale	1.000	0.478	Tropical–sub-polar
Humpback Whale	0.608	0.849	Tropical–polar
Striped Dolphin	**0.000**	1.000	Tropical–warm temperate
Fraser's Dolphin	1.000	1.226	Tropical–sub-tropical
Pygmy sperm Whale	0.378	1.000	Tropical–warm temperate

Bold indicates significant differences in strandings event frequency from chance.

common dolphins in north-west Scotland (Evans, 1980), although this assumes that all species identifications within this dataset were correct. This may be an issue with opportunistically collected data, particularly if some of the observations were recorded by inexperienced observers. However, other potentially more reliable data recorded by experienced observers suggest a similar relationship between these two species in previous years. For example, at a monitoring site in the study area (Handa Island – see Fig. 1 for location) between 1987 and 1991, 22.0 white-beaked dolphins were recorded per 100 days of observations, in comparison to

0.6 common dolphins (Evans, 1992). Similarly, systematic surveys between 1979 and 1999 recorded a total of 531 sightings of white-beaked dolphins, with abundances reaching over 0.1 individuals per kilometre in some areas, including areas covered by ferry surveys in summers 2002 and 2003. In contrast, there were only 101 sightings of common dolphins during the same surveys, almost all of which were recorded outside the area covered by the surveys conducted in 2002 and 2003 (Pollock et al., 2000). While there is variation in the time of year covered by different studies, white-beaked dolphins were previously most frequently sighted in near-shore waters between June and October (Evans, 1992), a period almost completely covered by our surveys (May to September). Therefore, the very low number of sightings of white-beaked in comparison to common dolphins in 2002 and 2003 is unlikely to be an artefact of the timing of the surveys.

4. Discussion

The changes in relative strandings and sightings frequencies of common and white-beaked dolphins are consistent with the predicted changes in the cetacean community with increased water temperatures, as is the occurrence of new, warm water species in north-west Scotland. At least one of these new warm water species, the striped dolphin, now appears to be a regular member of this community, with twice as many strandings since 1998 as white-beaked dolphins and with occasional sightings at sea, despite never having been recorded in Scottish waters prior to 1988 (Reid et al., 1993; Shrimpton and Parsons, 2000).

Based on this analysis, we suggest warming of local waters has, indeed, led to changes in the cetacean community of north-west Scotland, with a decline in occurrence of cold water species, an increase in the occurrence of existing warm water species and the addition of new warm water species to the community. If these waters continue to warm, for example at the rate of 0.2–0.4 °C per decade predicted from some oceanic climatic modelling (Fisheries Research Service, 2003), these changes are likely to continue. Additional warm water species will almost certainly be added to the community, and colder water species, such as the white-beaked dolphin, will almost certainly continue to decline in local occurrence and may eventually disappear from the north-west Scotland cetacean community.

Such alterations in cetacean communities have serious implications for their conservation for at least three reasons. Firstly, it may lead to populations of cetaceans moving out of, or becoming extirpated from, areas that have been specifically designated for their conservation based on previous patterns of distribution, such as marine special areas of conservation (mSACs) (Hastie et al., 2003), as they track changes in the availability of suitable habitats or are competitively excluded by incoming species. This is particularly important given the time frame in which recent changes in north-west Scotland seem to have occurred, less than 15 years, and the length of time it takes to gather supporting evidence and set up such protected areas.

Secondly, while warmer water species may benefit through an expanded range as temperatures increase, the opposite will happen for colder water species and their distribution is likely to shift polewards resulting in a reduced global range (Harwood, 2001). The decline in the strandings frequency, sighting frequency and relative abundance of white-beaked dolphins in north-west Scotland may be the first direct evidence that this is indeed happening in a cetacean species. This may be particularly relevant to colder water species, such as the white-beaked dolphin, that primarily occur in shelf waters less than 200 m deep. In the North Atlantic, such species are probably divided into a number of relatively isolated populations, each restricted to a shelf region isolated from other such regions by deep, oceanic waters. The shelf waters around the north-west Europe make up a substantial proportion of such habitat in the North Atlantic, making it a particularly important region for colder water shelf species.

However, around north-west Europe, these waters primarily occur south of 60°N (Fig. 3). As a result, there is little opportunity for shelf-living species restricted to colder waters, such as the white-beaked dolphin, to track their habitat northward as ocean climates change. Therefore, any reduction in their distribution in shelf waters around north-west Europe, as suggested by this study, will almost certainly result in a reduction in the total area where they occur. In particular, if the white-beaked dolphin is extirpated from waters south of

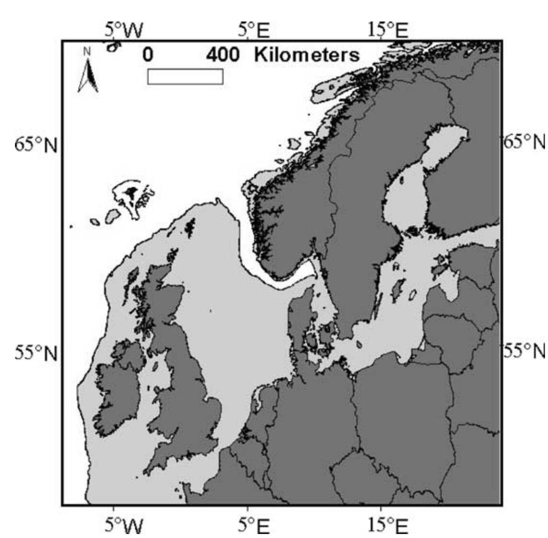


Fig. 3. Distribution of shelf waters (grey shading) around north-west Europe.

60°N due to continued ocean warming, the total area of suitable colder water shelf habitat around north-west Europe will decline dramatically to a very small fraction of its former amount, potentially leading to a dramatic decline in number of white-beaked dolphins occurring around north-west Europe.

Finally, any changes that occur in community structure may affect the ability of a strategy based on the previous structure to protect the species or populations involved. The relatively rapid changes in a cetacean community identified in this study suggest that continuous monitoring of cetacean community composition and structure should be an important component of any cetacean conservation strategy. Any changes in the local cetacean community that are detected during such monitoring should be fully investigated to assess their implications for both current and future conservation strategies.

The identification of changes in the cetacean community of north-west Scotland was possible only due to the existence of a long-term systematic strandings record and historical data on the relative occurrence of cetacean species in the area. Similar changes may well have occurred in other parts of the world, but remain undetected due to the lack of comparable long time series of data. In this respect, it is interesting to note that the first possible indication of change appeared in the strandings record rather than in the relative sightings frequency data. In addition, changes in relative abundance noted from sightings surveys were also reflected in changes in the strandings record. This highlights the importance of systematically recording strandings as an integral part of any programme aimed at monitoring the well-being of local cetacean communities.

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