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An assessment of some of the factors affecting observer efficacy during cetacean surveys in Canada's Pacific Region

Évaluation de certains facteurs touchant l'efficacité des observateurs pendant les recherches sur les cétacés menées au Canada, dans la région du Pacifique

Linda M. Nichol

Fisheries and Ocean Canada,
Science Branch, Conservation Biology Section,
Pacific Biological Station
Nanaimo, B.C.

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ABSTRACT

Sighting and effort data from five cetacean population assessment surveys made in the Pacific region were pooled and analysed to examine the effect of three environmental variables, Beaufort sea state, swell height, and lighting condition (cloudy or clear), on sightings per effort hour. Sightings per effort hour declined for all species and groupings with increasing sea state or swell height. The effect was most pronounced for small cetaceans (porpoise and dolphins). Lighting conditions appeared to also affect sightings per effort hour; however the number of hours of effort when skies were cloudy was almost three times greater than when it was clear. The type of visual cue that a species presents is also a factor that affects detectability of cetaceans. The results are discussed in the context of the effectiveness of mitigation procedures used during seismic surveys that rely on the observations of Marine Mammal Observers.

RÉSUMÉ

Les données sur les observations et les données d'effort tirées de cinq missions de recherche sur l'évaluation de la population de cétacés menées dans la région du Pacifique ont été mises en commun et analysées pour examiner l'effet de trois variables environnementales – état de la mer de Beaufort, hauteur de la houle et conditions de luminosité (nuageux ou dégagé) – sur les observations, par heure d'effort. Les observations par heure d'effort ont diminué pour toutes les espèces et tous les groupes à mesure que l'état de la mer ou la hauteur de la houle augmentait. L'effet était le plus prononcé chez les petits cétacés (marsouins et dauphins). Il semble également que les conditions de luminosité aient influé sur les observations par heure d'effort. Par contre, le nombre d'heures d'effort déployées par temps nuageux a été près de trois fois plus élevé que par temps dégagé. Le type de repère visuel d'une espèce constitue aussi un facteur qui a une incidence sur la détectabilité des cétacés. Les résultats font l'objet d'une discussion dans le contexte de l'efficacité des procédures d'atténuation utilisées pendant les levés sismiques qui reposent sur les observations des observateurs de mammifères marins.

INTRODUCTION

Canada and many other jurisdictions require mitigation procedures during seismic surveys that are intended to avoid marine mammals (Wier and Dolman 2007; DFO 2008). Sound reception is critically important to marine mammals, particularly cetaceans. These species rely on active acoustics (vocalizations, echolocation) and passive acoustics to navigate, locate conspecifics, maintain group cohesion, avoid predators and find prey. High intensity man-made sounds such as those produced during seismic surveys have the potential to affect these functions via physiological damage including permanent or temporary hearing threshold shifts or by masking of signal reception, and disruption of normal behaviour (Gordon *et al.* 2004; Madsen *et al.* 2006).

Mitigation procedures to avoid marine mammals used on seismic surveys (during daylight hours) rely on visual monitoring by a Marine Mammal Observer (MMO). The main element of this mitigation is the establishment of a safety zone which is a specified area defined by a radius that encircles the ship and the towed array. The task of the MMO is to visually monitor the safety zone in order to ensure the zone is clear of marine mammals (Weir and Dolman 2007). Mitigation procedures include intense visual scanning of the safety zone prior to start up of the array and implementing shut-down of the airgun array if a marine mammal is sighted in or approaching the safety zone (Wier and Dolman 2007; DFO 2008). The success of these mitigation procedures is dependent on a number of assumptions, in particular, the ability of an observer on a ship to successfully detect all marine mammals in or approaching the safety zone. Observer efficacy, however, is likely influenced by a number of factors including, environmental conditions, behaviour of the species, experience of the observer, elevation of the observation deck and the level of fatigue experienced by the observer (Barlow *et al.* 2001; Lawson and McQuinn 2004). Yet the effect of these factors on the success of mitigation procedures has yet to be critically evaluated.

In an effort to evaluate some of these factors, data collected during five ship-based cetacean population assessment surveys led by Fisheries and Oceans Canada (DFO) in Canada's Pacific waters in 2006, 2007 and 2008 were summarized and presented here to examine the effect of environmental variables on sightings per effort hour. Although the survey design and data collection procedures are somewhat different from that of a seismic survey, the results are discussed in the context of effectiveness of mitigation measures employed during a seismic survey.

METHODS

The data used to examine the effect of environmental variables on sighting rates were obtained from the datasets of five DFO cetacean population assessment surveys conducted in 2006, 2007, and 2008 along Canada's Pacific coast. Data collected during periods of *on effort* only were included in the analysis. *On effort* occurred when (1) the ship traveled along a designated transect, (2) sea state, according to the Beaufort scale of wind force, was < 5, (3) swell height was less than four metres, (4) visibility was ≥ 3 nautical miles (5.55 kilometres), and (4) two dedicated observers were stationed (one to port the other to starboard) on the observation deck or bridge and a data recorder was also stationed on the bridge to record environmental conditions and sightings of whales reported to them by the observers.

Observers used either Fujinon 7x50 binoculars with reticles, or Fujinon 25x150 MTM military binoculars with reticles ("Big Eyes") that were pedestal-mounted on the vessel's observation deck. Observers followed a scheduled rotation of 30 minutes scanning on the port side, 30 minutes on the starboard side and 30 minutes as data recorder. Thus each shift lasted 90 minutes. Each survey employed a team of eight to 15 observers which resulted in a maximum of three to four 90-minute shifts per observer per day. Each observer scanned a 100º area (from the bow to 90º from the ship's heading, plus an additional 10º overlap across the bow of the ship). The data recorder recorded sighting conditions every 30 minutes, or when conditions changed. Table 1 lists environmental variables recorded. The ship's position was recorded at approximately 30 second intervals through a GPS link and all environmental condition entries and sightings were linked by time to the ship's coordinates. The surveys were made from three Canadian Coast Guard ships; the *John P. Tully*, the *Tanu,* and the *Gordon Reid*. Elevation of observations and the numbers of observers on each survey are shown in Table 2.

Prior to analysis, effort hours and sightings were partitioned into *inshore* and *offshore* in GIS (ArcView). *Inshore* surveys referred to effort and sightings made in inside passages and channels. *Offshore* referred to open water areas more likely to be exposed to swell. Figure 1 illustrates the spatial extent of all the effort used in this analysis. Data were partitioned in this way because swell is not present in inshore areas and because some species occur only in the offshore areas, e.g. fin whales, sperm whales and Baird's beaked whales.

The data were then filtered to exclude periods of effort when observers used the Big Eye binoculars, to ensure the dataset included only effort and sightings made with equipment comparable to that likely to be available to an MMO on a seismic ship. Table 3 presents the final tally of effort hours which formed the basic dataset used in this analysis. The data from each cruise were pooled to increase sample size. This was justified because, the survey methodology among cruises was the same, the ships were similar with respect to observer elevation and the survey area (Pacific Region) was the same.

For analysis of sightings per effort hour, species were grouped as either small cetaceans (porpoise and dolphins) or large cetaceans (large whales) to increase sample size, although for species with a sufficient number of sightings (e.g. humpback whales), data were also presented separately. Table 4 lists the species and groupings recorded during the five cruises.

Sightings per effort hour were then computed, categorized by sea state (Beaufort), by swell height category, and by the combination of sea state and lighting conditions (termed weather in Table 1) (Table 1). In this last case, to examine the effect of lighting conditions, sightings and effort hours were grouped by sea state and then subdivided into either a *Clear* (0-20% cloud) or a *cloudy* (overcast, or light rain, or cloudy (81 to 99%)) category. Sightings and effort obtained during periods of other weather had to be excluded because there was limited effort when it was foggy or raining heavily, and because the other cloud cover category (21 to 80% cloud cover) was too broad for a useful comparison. Of the four environmental variables in Table 1, glare was not analysed because the sample size was very small. Finally to explore the effect of visual cues on detection, the frequency of sightings (by species) by visual cue was computed.

RESULTS

Offshore

A total of 1,218 sightings of cetaceans were logged during 390 hours of observation during five cruises. Sightings per effort hour declined as sea state increased for humpback whale sightings, for all large whales sightings grouped, and for porpoise and dolphin sightings grouped (Figure 2). This trend was most pronounced for porpoise and dolphin sightings. For humpback whales and all large whales, sightings per effort hour declined from Beaufort 0 to Beaufort 2. The distribution of effort hours by sea state is presented in Figure 3. Sightings per effort hour also declined as swell height increased. Sightings per effort hour were lower when swell was > 1 m than when it was less for both species groupings (Figure 4). Figure 5 presents the number of effort hours by swell height category. In almost all cases, more sightings per effort hour were obtained when lighting conditions were categorized as *cloudy*, than when they were *clear*, for each Beaufort state (Figure 6). However, there were 267 h categorized as *cloudy*, and only 96 h categorized as *clear* (Figure 7).

Inshore

A total of 84 sightings of cetaceans were obtained. The data set for inshore was limited (96 h), compared to 390 h in offshore regions. Effort and sightings at Beaufort 0 had to be excluded as there was only one hour of effort (Figure 9). Figure 8 suggests that sightings per effort hour declined with increasing Beaufort for all large whale sightings (which were almost all humpback whales in this case) and for all porpoise and dolphin sightings. There was too little effort when skies were *clear* to adequately assess the affect of lighting conditions.

Visual cues

For each sighting reported, observers recorded the visual cue that first alerted them to the animal. A blow was record as the first cue 74% of the time for humpback whales and 81% of time for fin whales. Other cues for humpback whales included body (14%), splash (9%) and breach (2%), whereas for fin whales the only other cue was body (18%). For porpoises and dolphins, body (52%) and splash (47%) were the most frequently reported cues (Table 5).

DISCUSSION

The purpose of this analysis of cetacean survey data was to examine the effect of some environmental variables, species type, and sighting cue on the ability of an observer to detect cetaceans and to then consider the implications of these results for visual monitoring of the safety zone during a seismic survey. Sightings per unit of effort can be used to examine broadly how detection changes with sighting conditions (Barlow *et al.* 2006). The results from the survey data analysed here indicate that increasing swell height and sea state affect the ability of observers to sight cetaceans (Barlow *et al.* 2001). Additionally lighting conditions categorize in this study as *cloudy* or *clear* affected sighting rates. Sighting rates were higher when skies were overcast than when they were *clear*, although the number of effort hours when skies were *clear* was considerably fewer than when *cloudy*. The effect of glare on sighting rates could not be assessed because of small sample size; however, glare is an important factor that can impair observation (Clarke 1982; Barlow *et al.* 2001).

Some species are easier to sight than others because of the visual cues they present (Clarke 1982; Barlow *et al.* 2001). In this study, sighting rates for porpoises and dolphins declined consistently with each increase in Beaufort category or swell height. Although there appears to have been a slight increase at Beaufort 4 (see Figure 2c), perhaps because Dall's porpoise and Pacific white-sided dolphins would at times approach the ship to ride the bow wave (Barlow *et al.* 2001). The sighting cues reported for porpoises and dolphins were almost exclusively a flash of body or splashes, cues that may be more easily missed at a distance than a large blow. Harbour porpoise are very difficult to spot and sighting rates for this species drop off rapidly with Beaufort states above 1, even in the absence of swell (Barlow 1988; Hammond *et al.* 1995; Olesiuk *et al.* 2002).

Sighting rates for large whales declined with increasing sea state or swell height but the effect of sea state alone was not evident above Beaufort 2. Most large whale sightings were first detected by a blow. A blow from a large whale is often silhouetted against the sky because of its height and is therefore more conspicuous and less likely to be obscured by a sea surface increasingly textured by waves, white crests and swells. Also, large cetaceans, merely by virtue of their size (e.g. humpback whale and fin whale, in this study), present a larger visual cue than a small cetacean. Humpback whales were most often seen first by a blow, but also by body which could be the back or raised flukes associated with a dive. Humpback whales also breach, providing another, though less frequently reported cue. It is likely that the multiple cues possible with this species made them more visible than other large cetaceans under a greater range of conditions.

Species specific swimming and diving behaviours affect species detection. Deep-diving species are easily missed because of the length of their dives and infrequent surfacing (Clarke 1982; Barlow and Gisiner 2006). During the five surveys analysed here, there were two sightings of Baird's beaked whales and six sightings of sperm whales. Sperm whales dives may range from 40 minutes to 2 hours, Baird's beaked whales for 30 to 60 minutes (Reeves *et al.* 2002). Sighting rates for beaked and bottle-nosed whales (family Ziphiidae) drop off rapidly with increasing sea state because these animals spend little time at the surface (median surface times are 2 to 2.5 minutes), and because they present a low profile (Barlow and Gisiner 2006; Barlow *et al.* 2006). Visual detection rates for these species during seismic surveys are estimated to be less than 2% because of the difficulty in detecting them under anything but ideal conditions (Barlow and Gisiner 2006). During cetacean surveys, the sighting rate for beaked whales at Beaufort 2 was half that at Beaufort 0 and by Beaufort 5 sighting rate had declined 10-fold (Barlow *et al.* 2006).

The present analysis did not examine the effect of observer fatigue on sighting rates, although this can be an important factor (Clarke 1982; Lawson and McQuinn 2004; Weir and Dolman 2007). During the cetacean population assessment surveys, observers were rotated every 30 minutes resulting in a shift length of 90-minutes per observer. As a result of the sizes of the observation teams, each observer had only three to four 90-minute shifts per day. In contrast, seismic surveys have one to three observers responsible for visual observations during daylight hours for the entire survey.

A maximum shift length of four hours has been recommended to reduce fatigue and its effect on mitigation (Lawson and McQuinn 2004; Weir and Dolman 2007).

There are other differences as well between the data collected during the five cetacean population assessment surveys analysed here and seismic surveys. During the cetacean surveys, the search area along the transect line extended to the full visible extent which was near the horizon (six nautical miles or 11 kilometres) if conditions were optimal. In contrast the safety zone around a seismic ship and array may have a radius of three kilometres and often less, although safety zones of five kilometres are reported (Rutenko *et al.* 2007; Weir and Dolman 2007). In addition, MMOs on seismic surveys should visually scan 360 degrees around the ship and array, whereas during these cetacean surveys the port and starboard observer together scanned 180 degrees. Environmental conditions particularly affect the distance at which sightings can be detected, and presumably the most distant part of the search area is affected first (Barlow *et al.* 2001). Thus at least part of the effect on sighting rates presented here would have arisen from the decline in distant sightings as conditions deteriorated. However, compared to data from a seismic survey, the extent of the effect of environmental conditions on sighting rates are likely under represented by these data because the cetacean surveys operated within a more limited range of environmental conditions than would a seismic survey. During the cetacean population assessment surveys, observation effort ceased if any of the following conditions occurred. Sea state reached Beaufort 5, swell height exceeded four metres, visibility was compromised by fog, mist or heavy rain, or if there was insufficient daylight (e.g. dawn, dusk, night). In contrast, seismic surveys may continue when sea state exceeds Beaufort 5 in some regions and when visibility is reduced (Barlow and Gisiner 2006; Weir and Dolman 2007) (Table 6).

Although there are differences in data collection between seismic surveys and the cetacean population assessment surveys used here, it is evident that environmental conditions do affect the ability of observers to sight cetaceans (Stone and Tasker 2006). Consequently during a seismic survey, not all cetaceans present in a safety zone may be detected. Cetaceans in the safety zone when the airgun array is operating may be exposed to sound levels that cause permanent or temporary hearing threshold shifts, or disrupt foraging or social behaviour or communication (Gordon *et al.* 2004; Madsen *et al.* 2006). Greater consideration of the role of environmental conditions on the effectiveness of mitigation would therefore seem warranted during the design of survey-specific mitigation measures, particularly in areas likely to be occupied by SARA-listed species or deep diving cetacean species. It may be appropriate to consider specifying the range of environmental conditions during which seismic surveying may occur in areas likely to be occupied by cryptic species. Finally, to further investigate and better assess the effects of environmental variables, sighting cues and species differences on observer efficacy during seismic surveys, it is recommended that future analyses be made using data collected by MMOs during seismic surveys.

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Table 1. Environmental condition factors recorded during surveys

Measure	Category	Description
Beaufort (sea state)	0	glassy mirror-like
	1	scale ripples
	2	small wavelets
	3	whitecaps, 1 - 5/sec
	4	frequent whitecaps
	5	many whitecaps/spray
Swell	0	No swell
	1	Low <1m short/average
	2	Low <1m long
	3	Moderate<2m short/average
	4	Moderate <2m, long
	5	Big 2-4m, short/average
	6	Big 2-4m, long
Weather	C	Cloudy (81-99%)
	CL	Clear-Blue Sky (0-20%)
	F	Fog
	FP	Fog Patches
	HF	Heavy Fog
	HR	Heavy Rain
	HZ	Haze
	LF	Lifted Fog
	LR	Light Rain
	MI	Mist
	OV	Overcast (100%)
	PC	Partly Cloudy (21-80%)
Glare	0	None
	1	Mild
	2	Moderate
	3	Severe

Table 2. Elevation of observation stations and the number of observers on five DFO cetacean population assessment surveys 2006 to 2008.

Cruise	Ship name	Elevation of observations on top deck (m)	Elevation of observations on bridge (m)	# of Marine Mammal Observers
Spring 2006	CCGS Tanu	10.3	7.7	10
Spring 2007	CCGS John P. Tully	15.5	12.8	12
Spring 2008	CCGS John P. Tully	15.5	12.8	14/15
Fall 2006	CCGS John P. Tully	15.5	12.8	8
Fall 2007	CCGS Gordon Reid	12.2	9.8	10

Table 3. Hours of survey effort

Cruise	Effort Hours inside waters	Effort Hours outside waters	Total Effort Hours
Spring 2006	15	137	152
Spring 2007	14	119	132
Spring 2008	20	71	92
Fall 2006	18	19	37
Fall 2007	30	44	74
TOTAL	97	390	487

Table 4. Species identified and groupings used in analysis.

Species Group / Common Name	Scientific Name
Small cetaceans (Porpoise and dolphins)	
Dall's porpoise	*Phocoenoides dalli*
Harbour porpoise	*Phocoena phocoena*
Pacific white-sided dolphin	*Lagenorhynchus obliquidens*
Unidentified dolphin	
Large cetaceans (large whales)	
Humpback whale	*Megaptera novaeangliae*
Fin whale	*Balaenoptera physalus*
Killer whale	*Orcinus orca*
Minke whale	*Balaenoptera acutorostrata*
Grey whale	*Eschrichtius robustus*
Sperm whale	*Physeter macrocephalus*
Baird's beaked whale	*Berardius bairdii*
Unidentified large whale	
Unidentified baleen whale	
Like humpback whale	
Like fin whale	
Like minke whale	

Table 5. All Cetacean sightings categorized by the initial visual cue observers recorded, and the percent of all sightings of a species or species group by cue type.

	Fin whale		Humpback whale		All large whales		Dall's porpoise		Pacific white-sided dolphin		All porpoise and dolphins	
Cue	sightings	%	sightings	%	sightings	%	sightings	%	sightings	%	sightings	%
Blow	82	81%	534	74%	837	78%	1	1%	3	6%	5	3%
Body	18	18%	98	14%	140	13%	49	52%	29	60%	89	56%
Breach			11	2%	13	1%						
fin			8	1%	8	1%						
Splash	1	1%	68	9%	71	7%	44	47%	15	31%	64	40%
Unknown			0				0		1	2%	2	1%
TOTAL	101		719		1069		94		48		160	

Table 6. Hours of monitoring effort by marine mammal observers when airgun arrays were active (including ramp-up periods), stratified by Beaufort sea state. Average Beaufort sea state is a time-weighted average. Data from Barlow and Gisiner (2006).

	Beaufort sea state											
Project area	0	1	2	3	4	5	6	7	8	Average Beaufort	Reference	Total hours
Northern Gulf of Mexico	0.0	0.0	8.8	7.8	0.8	0.0	0.0	0.0	0.0	2.5	LGL (2003)	17.4
Hess Deep/E. tropical Pacific	0.5	0.0	0.0	13.3	38.0	38.8	8.4	0.0	0.0	4.4	Smultea and Holst (2003)	99.1
Storegga Slide/Norway	0.5	8.7	25.2	33.2	56.7	59.6	61.8	18.3	1.9	4.5	MacLean and Haley (2004)	265.9
Mid-Atlantic Ridge	0.0	0.0	0.0	1.3	6.0	7.2	7.7	0.1	0.0	5.0	Holst (2004)	22.4

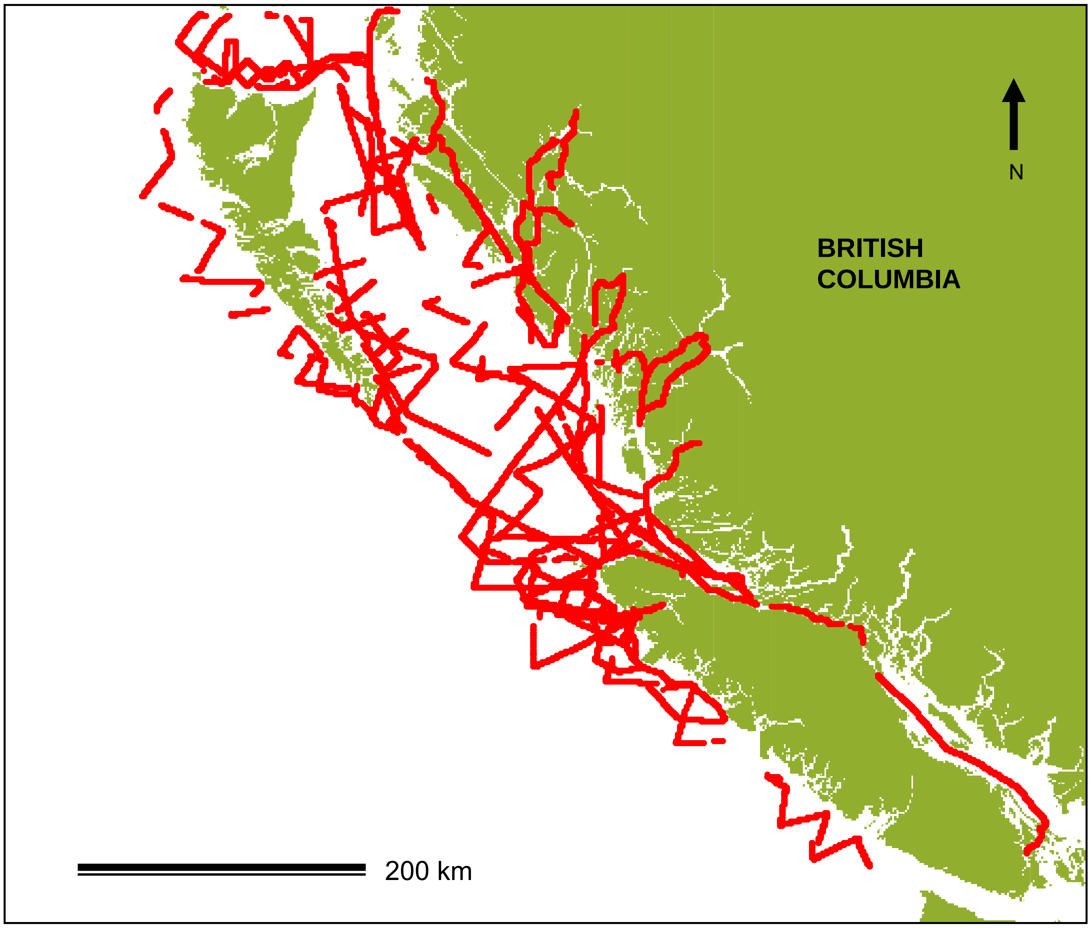

Figure 1. Spatial extent of dedicated effort from five DFO cetacean ship surveys (2006 to 2008).

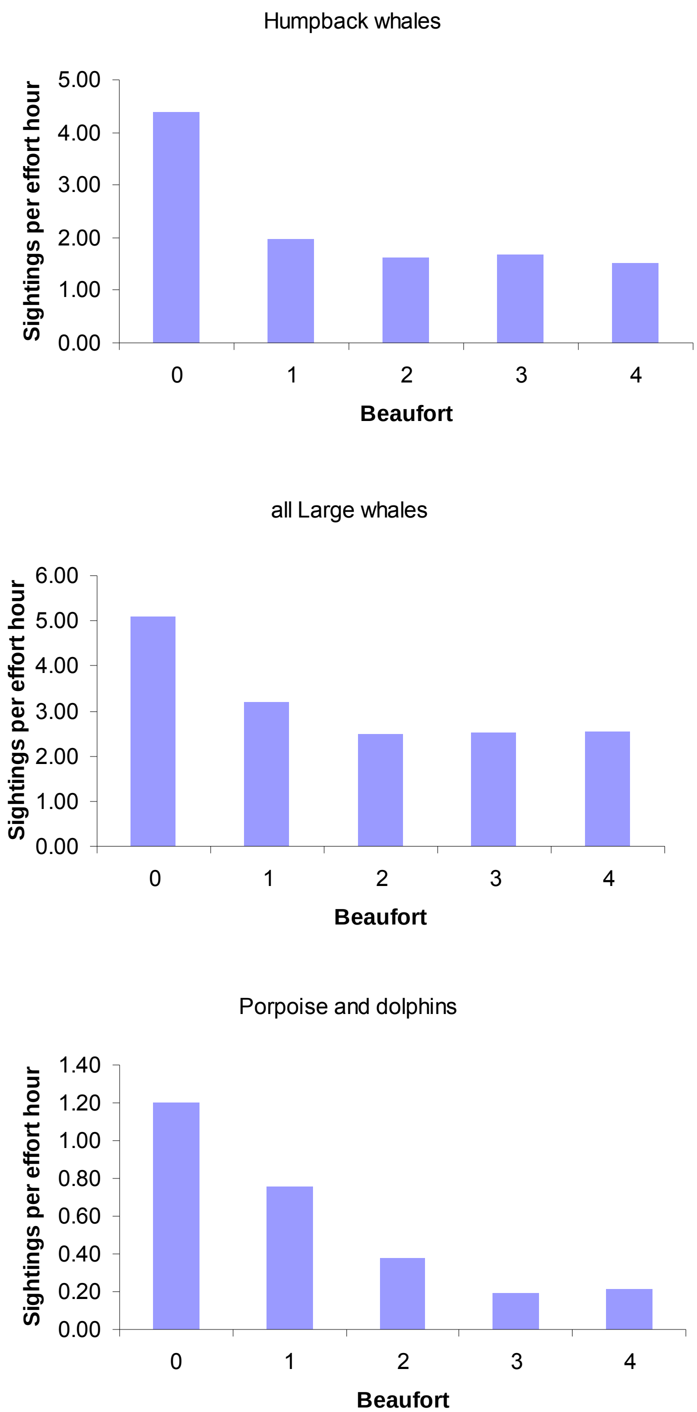

Figure 2. *Offshore*. Sightings per effort hour of a) Humpback whales, n = 695 sightings b) all large whales n = 1053 sightings and c) all porpoise and dolphins n = 152 sightings by Beaufort sea state.

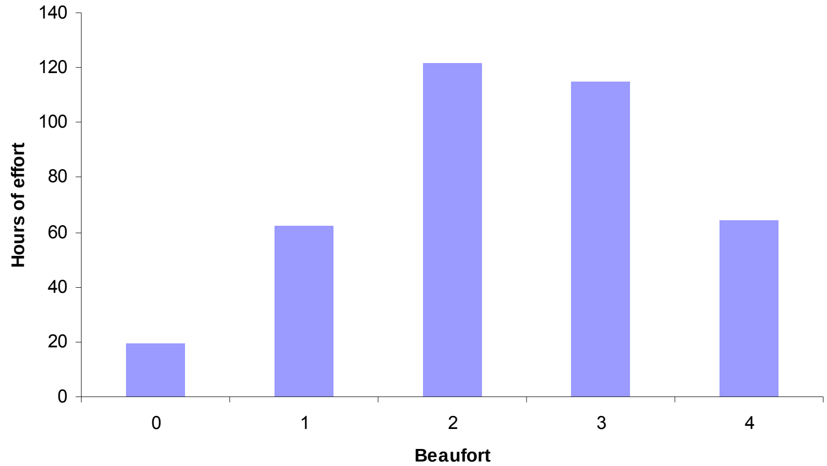

Figure 3. *Offshore*. Hours of survey effort by Beaufort sea state category.

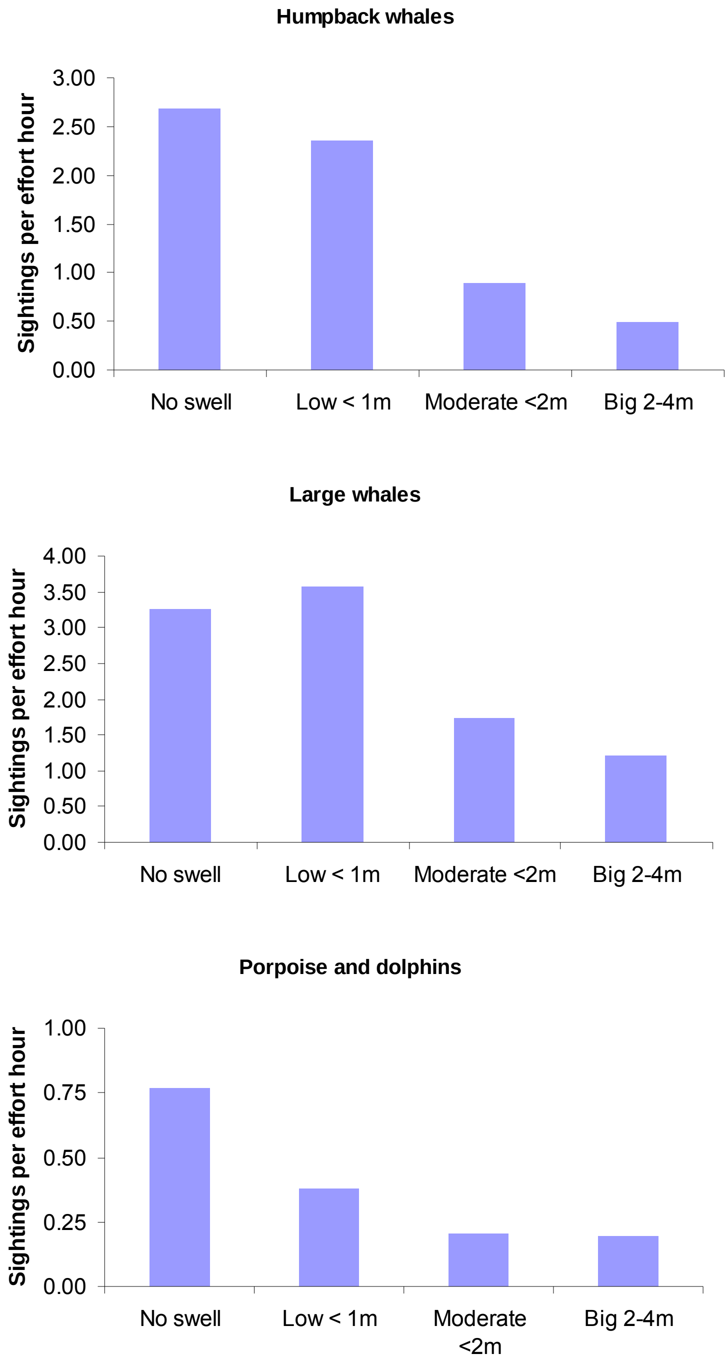

Figure 4. *Offshore.* Sightings per effort hour of a) Humpback whales, n = 695 sightings b) all large whales n = 1053 sightings and c) all porpoise and dolphins n = 149 sightings, by swell height category during five cetacean research cruises 2006 to 2008.

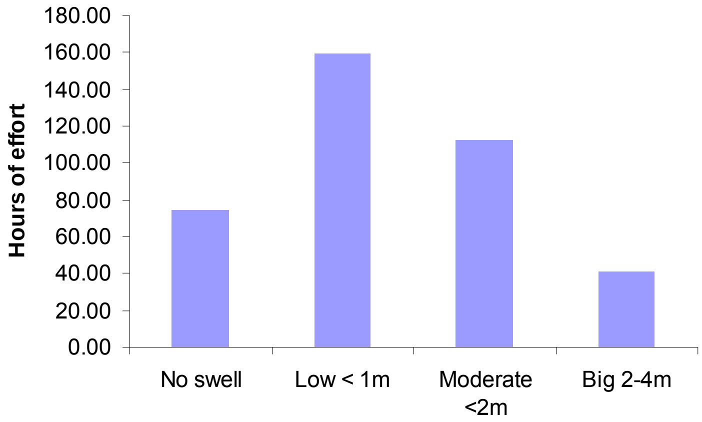

Figure 5. *Offshore.* Hours of survey effort categorized by swell height category.

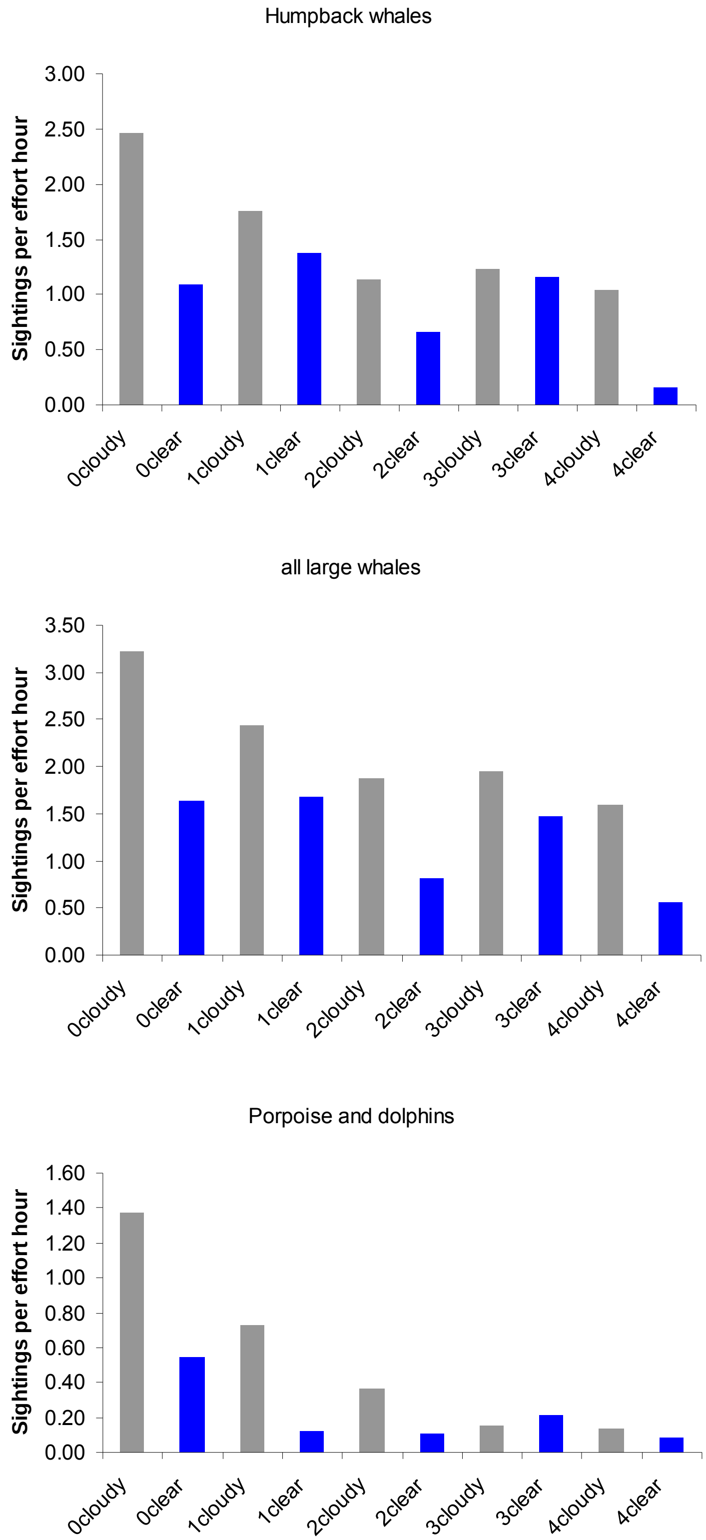

Figure 6. *Offshore.* Sightings per effort hour of a) Humpback whales, n= 439 sightings b) all large whales n= 651 sightings and c) all porpoise and dolphins n= 120 sightings, by categories of Beaufort (0 to 4) and lighting (cloudy or clear).

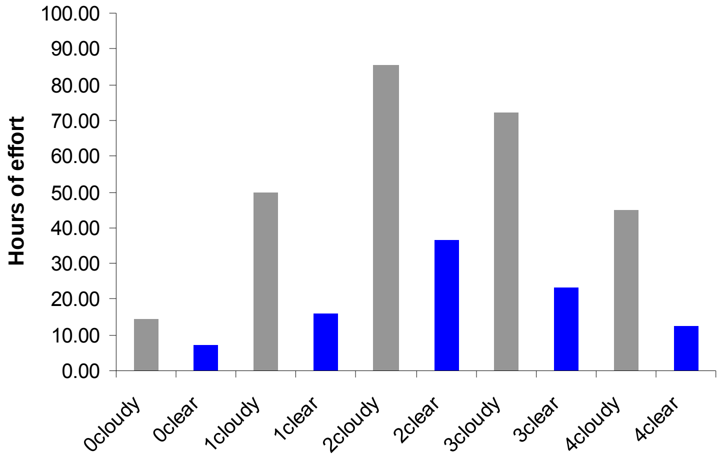

Figure 7. *Offshore.* Hours of survey effort by Beaufort and lighting (cloudy or clear) category.

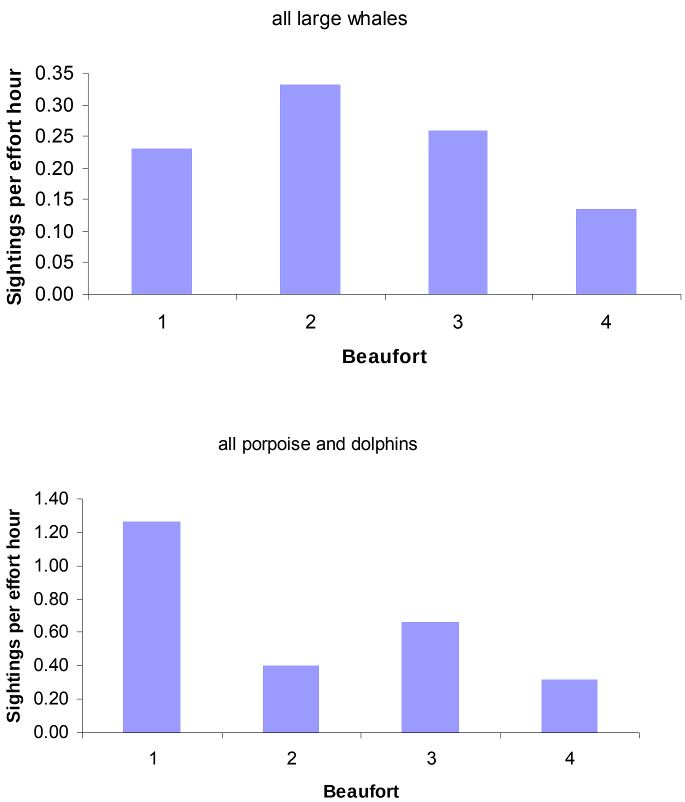

Figure 8. *Inshore.* Sightings per effort hour a) all large whale sightings n = 23, b) all porpoise and dolphin sightings n = 61 grouped by Beaufort sea state.

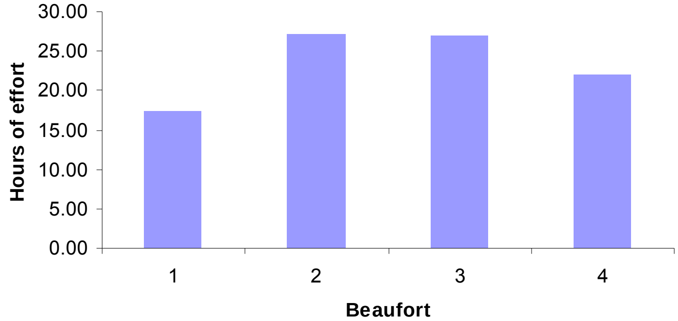

Figure 9. *Inshore.* Hours of effort grouped by Beaufort sea state.