Estimation of $g(0)$ for bottlenose dolphin, grey seal, and harbour porpoise in Cardigan Bay SAC.

By

Neal Reay

• PRIFYSGOL CYMRU •
UNIVERSITY OF WALES
BANGOR
1884

University of Wales, Bangor
Master of Science Thesis
Marine Mammal Science
2005

DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Signed …………………………………………… (candidate)

Date ……………………………………………

STATEMENT 1

This dissertation is being submitted in partial fulfilment of the requirements for the degree of

……………………………………….. (insert MA, MSc etc., as appropriate)

Signed …………………………………………… (candidate)

Date ……………………………………………

STATEMENT 2

This dissertation is the result of my own independent work/investigation, except where otherwise stated. Other sources are acknowledged by footnotes giving explicit references. A bibliography is appended.

Signed …………………………………………… (candidate)

Date ……………………………………………

STATEMENT 3

I hereby give consent for my dissertation, if accepted, to be available for photocopying and for inter-library loan, and for the title and summary to be made available to outside organisations.

Signed …………………………………………… (candidate)

Date ……………………………………………

ABSTRACT

With the current shift in management strategies towards the use of Marine Protected Areas (MPAs) to conserve species of marine mammals and their habitats, there comes the need for accurate, annual abundance estimates of species within MPAs to gain insight as to the species status, and the effectiveness of management strategies. Line transect surveys used to estimate marine mammal abundance assume detection on the trackline is unity ($g(0)=1$), which is rarely the case for marine mammals. If not accounted for, abundance estimates will be negatively biased by a factor proportional to the real value of $g(0)$. Dual platform, line transect surveys were conducted over 3 consecutive summers (2003-2005) within Cardigan Bay SAC to estimate $g(0)$ for bottlenose dolphin *Tursiops truncatus,* grey seal *Halichoerus grypus,* and harbour porpoise *Phocoena phocoena.* Environmental covariates were recorded with each sighting to allow for the inclusion of covariates in the analysis to reduce the effect of detection bias. The data from the 2003 and 2004 surveys was pooled due to poor sample size. Analysis using DISTANCE 5.0 revealed that $g(0)$ (NB: significant covariates in brackets) for bottlenose dolphin to be 0.705 (group size) in the 2003/04 surveys and 0.941 (group size, sea state, and observer experience) in the 2005 surveys. Esumates of $g(0)$ for grey seal were 0.815 (no significant covariates) for the 2003/04 surveys and 0.934 (observer experience) for the 2005 surveys. Estimates of $g(0)$ for harbour porpoise were 0.728 (group size) for the 2003/04 surveys and 0.811 (group size) for the 2005 surveys. The study revealed that $g(0)$ varied greatly between species and between years with variations in sample size and surveys conditions greatly affecting estimates. As result researchers should always calculate $g(0)$ for each survey and incorporate as many covariates as possible to reduce detection bias.

CONTENTS

LIST OF TABLES

Table No. *Page No.*

LIST OF FIGURES

Figure No. *Page No.*

LIST OF APPENDICIES

LIST OF DEFINITIONS AND ABBREVIATIONS

Definitions:

***g*(*x*)**	The probability of detecting and animal at perpendicular distance *x* from the transect line
g(0)	The probability of detecting an animal on the transect line

Abbreviations

MPA	Marine Protected Area
SAC	Special Area of Conservation
cSAC	Candidate Special Area of Conservation
IO	Independent Observer
MR	Mark –Recapture
MRDS	Mark-Recapture Distance Sampling

ACKNOWLEDGEMENTS

Firstly I would like to thank the Seawatch Foundation and Cardigan Bay Marine Wildlife Centre for making this study possible. A must also say a hearty thank you to all of the following people:

To my supervisors, Fernando Urgate and John Goold, for all there advice, notes on draft manuscripts, and general tolerance of my endless e mails! To Sharon Laing, who out of the kindness of her heart gave me some much needed words of wisdom on the statistical side of distance sampling, as well as passing judgement on previous drafts. To the course administrator Sally Wells, for putting up with my intolerable forgetfulness, and for providing a friendly face when things got stressed at the end. To Peter Evans and everyone at the Seawatch Foundation, particularly Tom, Eleanor, Hannah and Helen who made me feel at home, made me laugh, and were able to provide me with anything I asked for. To all the observers and crew aboard the *Sulaire* and *Dunbar Castle II* whose input has proved invaluable. To Stu, Lewis, Ed, Les, and Bran for making my time at the fort the best one yet. To my all my course mates particularly Nicola, for putting up with me for a fourth year, Ro Hickey for being one of the funniest men you'll ever meet, to Mercedes for steeling all my desk space at New Quay. You are a class bunch! To my Mum and Dad who were always on the end of the phone for a bit of moral (and financial) support. To my brother Martin and his lovely wife Sam, for letting me stay at their place to finish off my work next to the beach. And last but no means least, my awesome girlfriend Caroline for being the best thing since bread came sliced! I couldn't have done it without you.

1. INTRODUCTION

1. 1 SPECIAL AREAS OF CONSERVATION (SAC)

Management efforts to conserve marine mammal populations vary throughout the world. Efforts were originally directed towards single species conservation, as and when it became apparent that a particular species required protection (Hooker & Gerber 2004). However, in recent years there has been shift in the focus to the importance of protecting key marine mammal habitats in an effort to conserve the species contained within them (Wilson *et al.* 2004). This approach involves establishing a network of marine protected areas (MPA's) which have been defined by the World Conservation Union (IUCN) as "an area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical, and cultural features, which has been reserved by law or other effective means to protect part, or all, of the enclosed environment." (Hoyt 2005).

The European Community adopted the European Union Council Habitat Directive (92/43/EEC) in 1992, with the main objective to promote and preserve biodiversity, and to aim conservation efforts of the restoration of threatened or rare habitats and species, to there natural potential. The habitats directive initiated the development of a network of protected areas known as Special Areas of Conservation (SAC's) that would become collectively known as the Natura 2000 network. The key species listed within Annex II of the Habitats Directive are identified as being of community interest, whose conservation requires the formulation of SAC's (Hoyt 2005). There are 5 species of cetaceans and pinnipeds that reside in European waters, listed under Annex II of the Habitats Directive. These are bottlenose dolphin *Tursiops truncatus,* harbour porpoise *Phocoena phocoena*, grey seal *Halichoerus grypus,* harbour seal *Phoca vitulina,* and the ringed seal *Phoca hispida.* Furthermore, all cetacea found within European waters are listed under Annex IV of the Habitats Directive as being in need of strict protection.

Sites which contained species listed under Annexes I and II of the habitats directive were selected by member states of the EU, for consideration by the European Commission as candidate SAC (cSAC). Within the UK there are currently 3 cSAC known to contain *T. truncatus,* 8 cSAC known to contain *H. grypus,* and 7 cSAC known to contain *P. vitulina.* However, there are currently no cSACs specifically allocated for the conservation of *P. phoceona* in UK waters.

The immediate implications of a site being selected as a cSAC requires the development of specific management plans for the conservation of both the habitat, and the organisms contained within it. The authorities responsible for managing the site have to prove that the cSAC plays a critical role in the life cycle of a particular population before it is granted full SAC status; only then will the full conservation strategies for the species within the site by put into action. An example of such a site can be found in Cardigan Bay, West Wales, which was granted full SAC status in 2004 due to the resident population of bottlenose dolphins found to inhabit its waters throughout the year.

1.2 MARINE MAMMALS IN CARDIGAN BAY SAC

1.2.1 BOTTLENOSE DOLPHIN – Tursiops Truncatus

Bottlenose dolphin, *Tursiops truncatus,* are among the best studied species of marine mammal known to man (Wells and Scott 2002), This can be attributed to their cosmopolitan, and often coastal distribution throughout the world’s oceans and oceanaria (Shane *et al.* 1986). Despite the broad, global distribution of this species, they are often found in small isolated or semi-isolated populations that range across specific areas of coastline (Constantine *et al.* 2004), such as the Cardigan Bay, Wales. The number of animals in the Cardigan Bay population is estimated to be less than 200 animals (de Boer and Simmonds 2003)

1.2.1.1 Appearance

Adult bottlenose dolphins range in size from approximately 2 - 4.1m in length depending in geographic region (Connor *et al.* 2000). Bottlenose dolphins in the north-eastern Atlantic region are among the largest of the all the bottlenose populations with adult males frequently exceeding 3.5m in length. They are distinguishably by their medium size, dark colouration, moderately curved dorsal fin, and clear differentiation between the melon and the short beak (Wells and Scott 2002) (Figure 1.1) Estimates of the number of bottlenose dolphin in Cardigan Bay SAC achieved from photo ID studies range from 44-131 animals (Grellier *et al.* 1995).

Figure 1.1: A group of bottlenose dolphins surfacing for air in Cardigan Bay SAC. Image courtesy of Peter Evans/Seawatch Foundation (www.seawatchfoundation.org.uk)

1.2.1.2 Feeding

The diets of bottlenose dolphin have been extensively analysed across the bulk of their worldwide distribution. Walker *et al.* (1999) studied the dental isotopic signatures of western North Atlantic bottlenose dolphins spanning a 100 year period, and concluded that inshore populations prefer fish as their main food source, and offshore populations have a prevalence of squid in their diet. However, numerous studies have shown that diet varies between each studied region depending on the food resources available (Wells and Scott 2002). Bottlenose dolphins the Mediterranean Sea depend on fish, namely Hake *Merluccius merluccius,* as their main source of food (Blanco *et al.* 2001) whereas bottlenose dolphin in Scotland tend to prey on cod (*Gadus morhua*), saithe (*Pollichius virens*) and whiting (*Merlangius merlengus*) (Santos *et al.* 2001). Conversely, studies in the Indian Ocean indicate that cephalopods form a higher proportion of the diets of the bottlenose dolphin off eastern Africa (Cockcroft and Ross 1990). Disparity in the diets of bottlenose dolphins throughout the world indicate that differences in ranging pattern, local fish composition, animal size, and life stages all have implications on the target prey of individual dolphins (Shane *et al.* 1986).

1.2.1.3 Social Organisation

Bottlenose dolphins live in what is referred to as a fission-fusion society (Conner *et al.* 1999) comprising of relatively small groups characterised by fluid interactions, with some associations between specific animals/groups being repeated over long study periods (Würsig and Würsig 1977). Bottlenose dolphins tend to congregate in groups ranging from 2-15 animals, although groups in South Africa commonly comprise of 125-1000 animals (Shane *et al.* 1986). Dominance hierarchies are present amongst bottlenose dolphin groups, with large males dominating over all other group members (Wells and Scott 2002). Males often form complex unstable coalitions or alliances in order to compete with other male groups for access for females. Studies in western (Conner *et al.* 2001) and south-eastern Australia (Möller *et al.* 2001) have shown that unstable alliances developed between genetically unrelated males in order to herd and control female groups. However, studies on relatively isolated bottlenose dolphin population in Doubtful Sound, New Zealand, indicate stable male-male and female-female relationships with prevalence for constant companionship due to the ecological constraints of the environment (Lasseau *et al.* 2003). Strong associations between mothers and young are also frequently observed with records of young staying with their mothers for up to 7 ½ years (Shane *et al.*

1986). The social structure of a particular group depends on a whole variety of factors including age, sex, affiliation history, available resources, and the environment, all of which have different implications upon each population

1.2.2 GREY SEAL– Halichoerus grypus

The grey seal, *Halichoerus grypus,* is only found in the northern Hemisphere, colonizing the coastlines of the North Atlantic and Baltic Sea (Hall 2002). In 2003 there was an estimated worldwide population of 200,000 grey seal (Bossetti and Pearce 2003) with 110,000 animals in British population (Hall 2002). There are an estimated 5,000 grey seal in the SW Wales population which include seals from Cardigan Bay SAC (Countryside Council for Wales 2005)

1.2.6 Appearance

Grey seals are moderately sized phocid seals with streamlined bodies, with large eyes and nose (Figure 1.2). Pups are born with white fur, which turns progressively greyer within 3 weeks from birth. There is great discrepancy between adult grey seal coloration although male grey seal, known as ‘bulls’, grow to approximately 2.7m and are generally darker than females. Females are smaller than males (1.7m) and tend to be a grey/tan colour with spots on their dorsal surface.

1.2.7 Feeding

Grey seals around Orkney and the Outer Hebrides have been reported to feed indiscriminately on whiting and cod all year round (Hammond *et al.* 1994a; Hammond *et al.* 1994b). However, grey seals in these studies showed a tendency to selectively feed on sand eels *Ammodytes sp.* over other marine prey. Gadoids, such as whiting, cod and haddock, contain relatively low energy densities of <800kcal kg^{-1}, compared to plaice (<950 kcal kg^{-1}), and sandeels (around 1100 kcal kg^{-1}) (Wilson *et al.* 2002) and thus it has been suggested that where possible, grey seal will selectively prey on nutritionally beneficial species.

Figure 1.2: A grey seal, *Halichoerus gyrpus,* resting at the sea surface between dives. Image courtesy of www.bbc.co.uk/wales

1.2.8 Life History

Female grey seals give birth to 1 pup a year in the autumn, with pups weighing between 11-20kg at birth (Hall 2002). The pup mortality of grey seals is a major influencing factor that governs the status of breeding population between years. The level of pup mortality can vary greatly between years depending on the level of environmental and behavioural disturbance imposed on the mother and calf during the first 2 months following birth. Studies on grey seal in Scotland revealed that irrespective of pup condition, the odds of survival for female pups was 3.37 times higher than that of males (Hall *et al.* 2001). Approximately 66 pups are born each year within Cardigan Bay SAC although it is assumed that only 65% survive the first year (Countryside Council for Wales 2005). Grey seal milk is extremely lipid rich (50-65%), and during the lactation period (approx 18 days) pups quadruple their weight to 40kg (Hall 2002). Following weaning grey seal undergo a post-weaning fasting process which has been suggested to aid the development of the diving behaviour, which subsequently improves the chances of grey seal pups foraging for themselves (Hall 2002). The current conservation status of grey seals in Wales is good (Countryside Council for Wales 2005).

1.2.9 HARBOUR PORPOISE – Phocoena Phocoena

The harbour porpoise (*Phocoena phocoena*) is a small coastal odontocete whose primary distribution encompasses the temperate and sub-arctic waters of the northern hemisphere, including the North Pacific, North Atlantic, and Black Sea (Bjørge and Tolley 2002).

1.2.10 Appearance

The harbour porpoise is the smallest cetacean in the European Atlantic and is characterized by a small, rotund body, with a rounded head with no beak (Cresswell and Walker 2001). Their most identifiable feature in the field is a small, low, triangular, centrally placed dorsal fin. The dorsal surface of the harbour porpoise is dark grey which fades to light grey/white on the underbelly (Bjørge and Tolley 2002). Males can grow to 145cm and are generally smaller than females, who have been reported reaching nearly 2m in length (Read and Holn 1995).

Figure 1.3: The dorsal surface of a submerged harbour porpoise. Image courtesy of I. Berks/Seawatch Foundation (www.seawatchfoundation.org.uk)

1.2.11 Feeding

The diet of harbour porpoise, like bottlenose dolphins is based almost entirely around fish and squid (Bjørge and Tolley 2002) and evidence suggests that adult harbour porpoise may spend large amounts of time foraging at depth as the remains of benthic scavengers and demersel fish have been found in the stomachs of entangled porpoises (Westgate *et al.* 1995). Harbour porpoise calves in the Bay of Fundy are reported to prey upon euphasiids such as *Meganyctiphanes norvegica* during weaning before moving onto larger prey items (Smith and Read 1992). Adult harbour porpoise have a high energetic turnover due a short lifetime and annual reproduction (Jones 2004), and generally prey on fish with high lipid contents. For example, the stomach contents of 138 harbour porpoise from the Gulf of St. Lawrence revealed that capelin (*Mallotus villotus*) and Atlantic herring (*Clupea harengus*) formed >80% of the calorific contribution to the diet of the porpoise (Fontaine *et al.* 1994). The dominant prey species of harbour porpoise is likely to vary between study regions, depending on the prey composition of each area.

1.2.12 Behaviour and Life History

Behavioural observations of harbour porpoise in the wild are particularly difficult due to their inconspicuous surfacing behaviour and their avoidance of approaching boats (Cresswell and Walker 2001). When surfacing they expose their dorsal surface and fin for a brief moment and are rarely seen breaching (Bjørge and Tolley 2002). Harbour porpoise are normally found in small groups of 1-3 animals and tend to migrate parallel to the coast (Bjørge and Tolley 2002).

Harbour porpoise reproduce annually, with a gestation period of 10.5 months (Read and Holn 1995). Calving season usually occurs within the months of May to August and calves are usually 70-75cm at birth (Bjørge and Tolley 2002). The age of sexual maturity for harbour porpoise is around 3-4 years of age (Read and Holn 1995) with a mean life span of 8-10 years (Bjørge and Tolley 2002).

1.3 THREATS TO MARINE MAMMALS IN CARDIGAN BAY

The numerous threats to marine mammals have been well documented and tend to vary with geographic location. Even so they can be generally split into two categories: Direct threats, which present the risk of instant mortality to marine mammals, and indirect threats, which tend to cause accumulating harm with increasing exposure (Hooker and Gerber 2004).

1.3.1 Direct Threats

As marine mammals are air breathers, entanglement in fishing nets and marine debris pose the considerable threat of drowning. Between the years of 1990-1995 the major cause of death to cetaceans around English and Welsh Coasts was entanglement in fishing gear (Ceredigion County Council *et al.* 2001). The set gillnet fishery in the Celtic Sea is one of the major sources of entanglement of marine mammals near to Cardigan Bay SAC. Berrow *et al.* (1998) estimated that there is 1 seal entangled in the Celtic Sea gillnets for every 317.5 tonnes of fish caught. Furthermore it is suspected that there is substantial immigration of grey seals from the West Wales population into the Celtic Sea. Furthermore, a study by Tregenza *et al.* (1997) estimated that the annual bycatch of harbour porpoise in the Celtic Sea gillnet fishery is estimated at 2200 (95% CI 900-3500) per year. Walten (1997) used mtDNA sampling to suggest that the Celtic/Irish Sea harbour porpoise form a single population and thus the by-caught porpoise in the Celtic Sea represent part of the population of harbour porpoise that are found in Cardigan Bay SAC.

Another direct threat to marine mammals comes from collisions with boats and other marine craft. Although there has only ever been one harbour porpoise found with lesions suspected as being caused by a propeller (Ceredigion County Council *et al.* 2001) the ability for marine mammals to avoid collisions with boats depends on the density of the animals, the density of the boats, and whether there is sufficient water depth/space to avoid collision. Bristow (2004) reported that the leading authority responsible for managing Cardigan Bay SAC revealed plans to promote increased boating activity in and around the SAC. This may well serve to increase the threat posed to marine mammals in Cardigan Bay by ship collisions in the near future.

Although the potential threats to marine mammals through predation by sharks and other marine predators are well documented (Shane and Wells 2002), there are no recorded predators of marine mammals in Cardigan Bay SAC. However, Patterson *et al.* (1998) suggested that bottlenose dolphins are capable of infanticide (killing other bottlenose dolphin calves) as well as attacking, and killing porpoises during violent interactions. This behaviour has not been reported in Cardigan Bay bottlenose dolphins.

1.3.2 Indirect Threats

There are a considerable number of indirect threats to marine mammals in Cardigan bay SAC. The resident bottlenose dolphin population attracts a considerable number of tourists to the area and subsequently a relatively high number of boats use the waters within SAC. The mere presence of tourist, and privately owned boats may well have a detrimental effect on the growth and development of marine mammals within the SAC. A study by Constantine *et al.* (2004) on the resting behaviour of bottlenose dolphins in New Zealand suggested that harassment by boats significantly reduces the resting time available for dolphins. Furthermore, a study by Hastie *et al.*(2003) suggest that the surfacing behaviour of bottlenose dolphins in the presence of boat traffic in the Moray Firth, Scotland by be detrimental to health as it prevents the animals from partaking in other important behaviour such as foraging. Strict guidelines are in place within the SAC which prevent the public from approaching and harassing the animals within prior consent, yet harassment amongst other factors, has the potential to threaten the health and stability of marine mammal populations.

Another commonly reported threat to marine mammals comes from the progressive degradation of marine mammal habitat (Hooker and Gerber 2004). This is a broad term that covers many aspects, such as the direct, physical destruction of habitat, increases in chemical pollutants, and increasing boating activity contributing to increases in noise pollution. Studies by Morris *et al.*

(1989) and Law *et al.* (1995) have revealed that unusually high levels of organochlorines are present in the blubber of stranded cetaceans from Cardigan Bay. Although it was assumed that this is a result of bioaccumulation through of PCB’s and DDT compounds in the prey items (Morris *et al.* 1989), rather worryingly, the organochlorine content found in ceteacean blubber cannot be presently explained by analysis of the food web alone (Law *et al.* 1995) and may be caused by another, unidentified source. High levels of organochlorines in marine mammals have been known to reduce the efficiency of the immune system at fighting disease. If this coupled with excessive prey depletion by local fisheries has the potential to greatly reduce the relative health of the marine mammal populations.

Physical habitat degradation is occurring within Cardigan Bay SAC. A whelk (*Buccinum undatum*) processing plant situated on Newquay headland is licensed to dump 2,000 tonnes of shell waste into the waters off Newquay headland each year (Ceredigion County Council *et al.* 2001). Bristow (2004) suggested that site usage of this area by bottlenose dolphin had declined since the volume of whelk shell dumped increased, although no correlation was found this aspect of site degradation requires consistent monitoring and may have the potential to threaten marine mammal populations in the area.

If not correctly managed, these indirect and direct threats may cause a shift in the habitat preference to outside the SAC or worse, trigger a decline in the numbers marine mammals within the whole of Cardigan Bay. In order to prevent this, constant monitoring of the numbers of marine mammals within Cardigan Bay SAC is required, and one of the most effective ways of achieving this is through abundance estimation.

1.4 ABUNDANCE ESTIMATION AND G(0)

One of the major goals for establishing marine protected area is to minimize the risk of extinction of the species contained within it (Hooker and Gerber 2004). The first step in managing these protected areas is to evaluate the status of the target species population contained within them. One of the main stays of this evaluation is abundance estimation of the population (Buckland *et al.* 2001; Cañadas *et al.* 2004). In order to assess the effectiveness of the MPA's, abundance estimates must be obtained annually, both prior to, and during the implementation of MPA laws in order to detect any trends in the population status and thus the effectiveness of the MPA. One of the most commonly used methods to gain an abundance estimate of a wild population is through line-transect distance sampling.

Distance sampling techniques are based on the measurement of sighting distances from a line or point, from which density and abundance of the target object can be estimated (Buckland *et al.* 2000). Line transect surveys are widely accepted as an efficient and robust means of distance sampling (Borchers *et al.* 1998a) and this methodology has been extensively employed to obtain estimates of cetacean abundance, through ship-based (Barlow 1988; Carretta *et al.* 2000; Gerrodette and Forcada 2002; Hammond *et al.* 2002; Cañadas *et al.* 2004) and aerial-based surveys (Barlow *et al.* 1988; Laake *et al.* 1997; Carretta *et al.* 1998; Palka 2005a; Scheidat *et al.* 2005).

The fundamental principle behind line transect surveys is that observers travel along a predetermined line through the chosen study area, and record the radial distance (r) and angle (θ) from the trackline to each sighting. From here the perpendicular distance (x) to the transect line can be calculated using simple trigonometry (Figure 1.4)

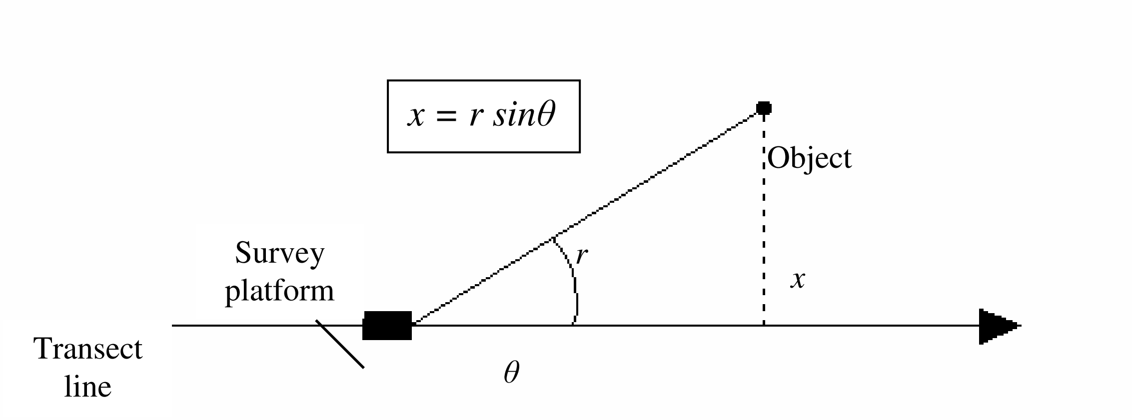

Figure 1.4: Calculation of the perpendicular sighting distance x of an object from the transect line using radial distance r and angle to sighting θ from the survey platform in a line transect survey.

The distance data collated during line transect surveys can be used to estimate the effective strip width (μ) of the survey (Cañadas *et al.* 2004). Effective strip width refers to the area of water either side of the transect line where observers detect objects with high efficiency. Beyond the effective strip width observers do not reliable detect all available animals. Buckland *et al.* (2001) give a formal definition of effective strip width (μ) as: the distance at which unseen animals closer to the line than μ equals the number of seen animals at distances greater than μ. Once μ has been established, estimates of density and abundance for the target species within the study area can be achieved. However, any estimates of density and abundance derived from line transect surveys will be inherently biased if 3 fundamental assumptions (listed below) are not met, or at least accounted for in the survey design (Laake 1999). The most important of these assumption in line transect theory is that all animals on (or close to) the trackline are detected with certainty. The probability of an animal being detected at perpendicular distance x from the transect line is often written as $g(x)$, or even $p(x)$, and is referred to as the detection function (Borchers 2005). Hence the probability of detecting an animal on the transect line, where distance $x = 0$, is referred to as $g(0)$. Thus, if the probability of detecting an animal on the trackline (at 0m from the trackline) is assumed to be certain, then the value of the detection function at distance zero is written $g(0) = 1$.

As previously mentioned, there are 3 fundamental assumptions of line transect theory that are listed below in order from the most critical to the least critical (Buckland *et al.* 2001)

1) Objects on the trackline are detected with a probability of $g(0) = 1$.
2) Objects are detected in their initial location prior to any responsive movement in relation to the survey platform.
3) All measurements of angles and distances are measured accurately.

Many of the early models derived to estimate density and abundance from distance sampling methodology (i.e. Burnham and Andersen 1974), form the foundations, upon which modern distance sampling theory is based. These models depend on the assumption that observers detect all objects on the trackline with certainty (*g*(0) = 1) however; this is rarely the case in the marine environment. The main reason why marine mammals are missed on the trackline is due to visibility bias (Laake 1999). Marsh and Sinclair (1989) recognised visibility bias comprised of two components: a) Availability bias and b) Perception bias. Availability bias occurs in marine mammal surveys when the animals are unavailable for detection as they are underwater whereas perception bias is as a result of the observers failing to detect the animals even though they available for detection (Borchers 2005). Visibility bias on the trackline results in observers failing to detect marine mammals at distance 0, and thus *g*(0) is frequently <1 (Laake *et al.* 1997). Any estimates of density and abundance when the probability of detection is *g*(0) < 1 at distance zero, will be underestimated by a factor proportional to the real value of *g*(0) (Borchers *et al.* 1998a; Buckland *et al.* 2004). For example estimates of *g*(0) for aerial surveys of harbour porpoise have been estimated to be as low as 0.236 (Palka 2005a) and therefore abundance estimates in this case would be underestimated by 76.4% since *g*(0) was assumed to be unity. It is imperative that accurate estimates of *g*(0) are incorporated into abundance estimations of marine mammal surveys in order for practical and successful management strategies to be implemented.

1.5 ESTIMATION OF G(0) AND ACCOUNTING FOR BIAS

The pressing problem of uncertain detection on the transect line resulted in the marriage of conventional distance sampling (CDS) techniques with mark-recapture (MR) principles resulting in survey techniques known as Mark-Recapture Distance Sampling (MRDS) (Buckland *et al.* 2001). These MRDS techniques use multiple observers to estimate *g(0)* using a variety of methods ranging from the simple to complex statistical procedures (Buckland *et al.* 2004).

The idea MRDS is that 2 observer platforms scan the study area simultaneously, with each platform being used to test the sighting efficiency of the other. This can be achieved by having 2 separate areas allocated as observation platforms aboard the same ship/plane, or by using 2 separate planes altogether. Either way this methodology hinges on the fact that each team is separated from any visual or auditory cues produced by the other team so that the probability of one team detecting an animal is independent of whether the animal is detected by the other team (Buckland and Turnock 1992; Buckland *et al.* 2001). Both teams of observers record detections that they make but can potentially detect/miss each available animal. As a result there are 3 possible outcomes for each detected animal (Canadas *et al.* 2004):

1 – Detected by team 1, Missed by team 2
2 – Missed by team 1, Detected by team 2
3 – Detected by team 1, Detected by team 2 (a duplicate)

It is then possible to test the trackline sighting efficiency of both teams, by investigating the total number of trackline sightings by one team that were duplicated by the other (Borchers *et al.* 1998a*;* Buckland et al. 2001)

Mark-recapture distance sampling techniques have been used to estimate g(0), density, and abundance of marine mammals in numerous formats. These include multiple observer ship based surveys (Barlow 1988; Hammond *et al.* 2002; Cañadas *et al.* 2004; Palka 2005b), multiple observer aerial surveys (Barlow *et al.* 1988; Laake *et al.* 1997; Grünkorn *et al.* 2005; Palka 2005a), combined ship and aerial surveys (Buckland and Turnock 1992), tandem aerial surveys (Carretta *et al.* 1998), aerial circle back methods (Scheidat 2005), and through passive acoustic methods (Lewis 2005).

The process of estimating $g(0)$ using mark-recapture techniques is somewhat complicated by another form of bias known as unmodelled heterogeneity (Borchers 2005). Unmodelled heterogeneity refers to the fact that some objects are more detectable at any given distance than others. For example, highly visible objects (e.g. large groups) tend to be detected by both teams of observers on dual platform surveys whereas inconspicuous objects (e.g. individual animals) tend to be missed by both (Buckland *et al.* 2001). Furthermore, the effect of bias from unmodelled heterogeneity varies with differing perpendicular distances from the trackline. Environmental variables, and variations in survey procedure all have the potential to introduce unmodelled heterogeneity into any estimates of $g(0)$ unless they are accounted for. Modern analysis techniques allow for the introduction of these variables as covariates into formulas used to estimate $g(0)$. There have been numerous covariates reported as having the potential to introduce bias into estimation of the detection function. These include perpendicular distance (Borchers *et al.* 1998a, 1998b; Hammond *et al.* 2002; Cañadas *et al.* 2004), Beaufort sea state (Evans and Hammond 2004; Beavers and Ramsey 1998, Barlow *et al.* 2001; Evans and Hammond 2004;), group size, observer ability (Beavers and Ramsey 1998; Palka 2000; Hammond *et al.* 2002;; Palka 2005b), vessel type (Hammond *et al.* 2002), surfacing behaviour (Evans and Hammond 2004; Cañadas *et al.* 2004, Palka 2005b), sun glare (Barlow *et al.* 1988; Cañadas *et al.* 2004), wind (Palka 2005b), and cloud cover (Carretta *et al.* 1998; Barlow *et al.* 1988).

Movement of animals prior to detection can potentially cause bias in density estimates if it is not accounted for in field protocols or analysis. In some marine mammal surveys, animals may be attracted to the observer prior to detection, which is likely to have a positive bias on estimated density $\hat{D}$ (Buckland *et al.* 2001) and bias any estimates of $g(0)$. In recent years, more robust methods have been developed to counteract and potential bias on estimates of $g(0)$ that may be caused by responsive movement towards the vessel (Buckland and Turnock 1992; Borchers *et al.* 1998a; Palka and Hammond 2001). These techniques depend on one team acting as the tracker platform, searching far ahead of the ship with binoculars, and tracking the detected animal/group until it is detected by the primary platform (Borchers *et al.* 1998a). This technique should be employed wherever possible but its use is somewhat limited on smaller vessels.

1.5.1 Estimation of g(0) in Cardigan Bay SAC

Cardigan Bay was allocated its special area of conservation (SAC) status due to the resident population of Bottlenose dolphins that reside within it waters. The management plan devised by Ceredigion County Council *et al.* (2001) states the key management objectives for conserving and monitoring the resident bottlenose dolphin population. The key attribute identified in the Section 4 of the Cardigan Bay SAC management plan is the establishment of mean bottlenose dolphin abundance within the waters of the SAC. The mean bottlenose dolphin abundance within the SAC will then be used as a baseline value (± upper and lower confidence limits) from which all subsequent abundance estimates will be compared against to assess the status of the Cardigan Bay population. In this context it is important to try and make abundance estimation as precise as possible. If for example, the effect of incomplete detection of bottlenose dolphins (and other marine mammals) on the trackline is not accounted for via approximation of $g(0)$ or assuming $g(0) = 1$, then all abundance estimates will be underestimated by a value proportional to the real value of $g(0)$ (Buckland *et al.* 2001).

Ship based line transect surveys of Cardigan Bay SAC are conducted annually by both the Cardigan Bay Marine Wildlife Centre and the Seawatch Foundation. However, to date there have been no direct estimates of $g(0)$ for bottlenose dolphin, harbour porpoise, or grey seal in Cardigan Bay. Estimates of $g(0)$ for bottlenose dolphin from ship based surveys in other areas indicate that $g(0)$ can range from as 0.69-0.99 (Palka 2005b). Estimates of $g(0)$ for harbour porpoise are more widely available, with estimates ranging from 0.4-0.78 (Barlow *et al.* 1997). Although there is considerable variation in estimates of $g(0)$ between surveys, the literature suggests that considerable bias can be introduced into abundance estimates of bottlenose dolphin and harbour porpoise, if uncertain detection on the trackline is not accounted for. There have been no estimates of $g(0)$ for grey seal reported in the literature as mark-recapture techniques through photo identification are often used to determine the status grey seal. Nevertheless the use of distance sampling techniques to estimate abundance may well serve as an alternative method from which comparison in abundance estimates from other mark-recapture can be drawn.

This study examines the data from multiple observer line transect surveys performed by the Cardigan Bay Marine Wildlife Centre (2003 and 2004) in conjunction with the Seawatch Foundation (2003-2005) over 3 consecutive summers within Cardigan Bay SAC. The aim of the study is to produce reliable estimates of $g(0)$ for bottlenose dolphin, harbour porpoise, and grey seal within the SAC, with the intention of indicating the potential bias imposed on abundance estimates for these 3 species when incomplete detection on the transect line is not accounted for.

2. METHODOLOGY

2.1 STUDY AREA

The study was carried out in the Cardigan Bay, Special Area of Conservation (SAC) (4º 37’02’’, 52º 14’47”) (Figure 2.1). The Cardigan Bay SAC is located on the southern region of Cardigan Bay, spanning southern Ceredigion and northern Pembrokeshire. Its landward boundary is defined by the coastal mean high water mark running from the village of Aberarth, Ceredigion, in the north to just south of the Teifi Estuary, Pembrokeshire (Ceredigion County Council *et al.* 2001). The site extends approximately 12 miles offshore and encompasses an area of approximately 370 square miles (958.6 km^2) (Countryside Council for Wales 2005).

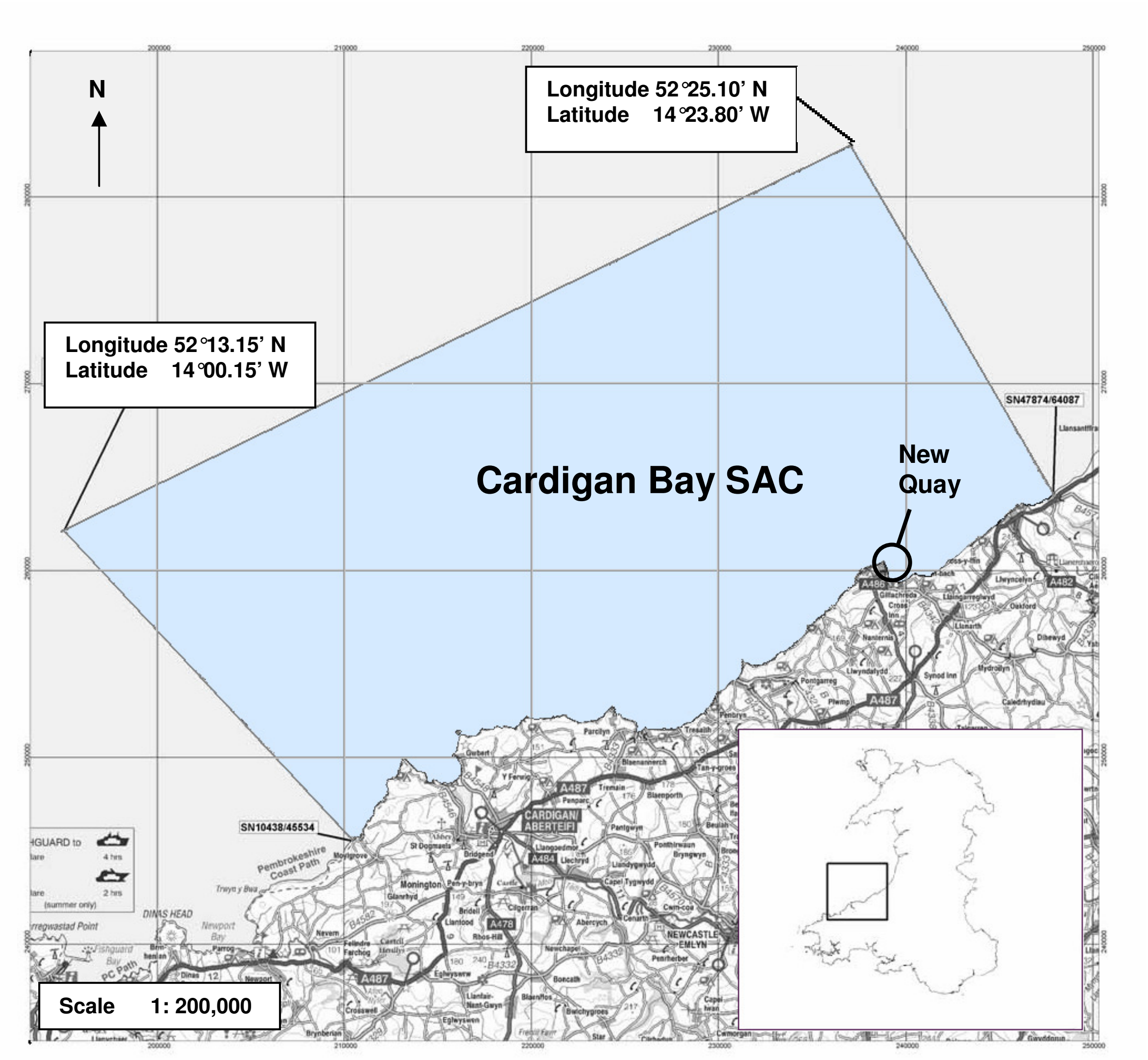

Figure 2.1: Location and boundaries of the study area, the Cardigan Bay Special Area of Conservation. Image adapted from (Countryside Council for Wales 2005).

The study was conducted out of the small fishing town of Newquay, located on the northern coastline of the SAC. The study includes data collected during line transect surveys within the SAC over three consecutive summers (June – September) in 2003, 2004, and 2005.

2.2 SURVEY DESIGN

A SAC was systematically split into a grid matrix of 13 line transects which spanned the entirety of the SAC (Figure 2.2). Before each research trip commenced, an individual line transect was chosen at random by a volunteer. Transects were only repeated if all other transects had already been surveyed to avoid the possibility of repeat sightings.

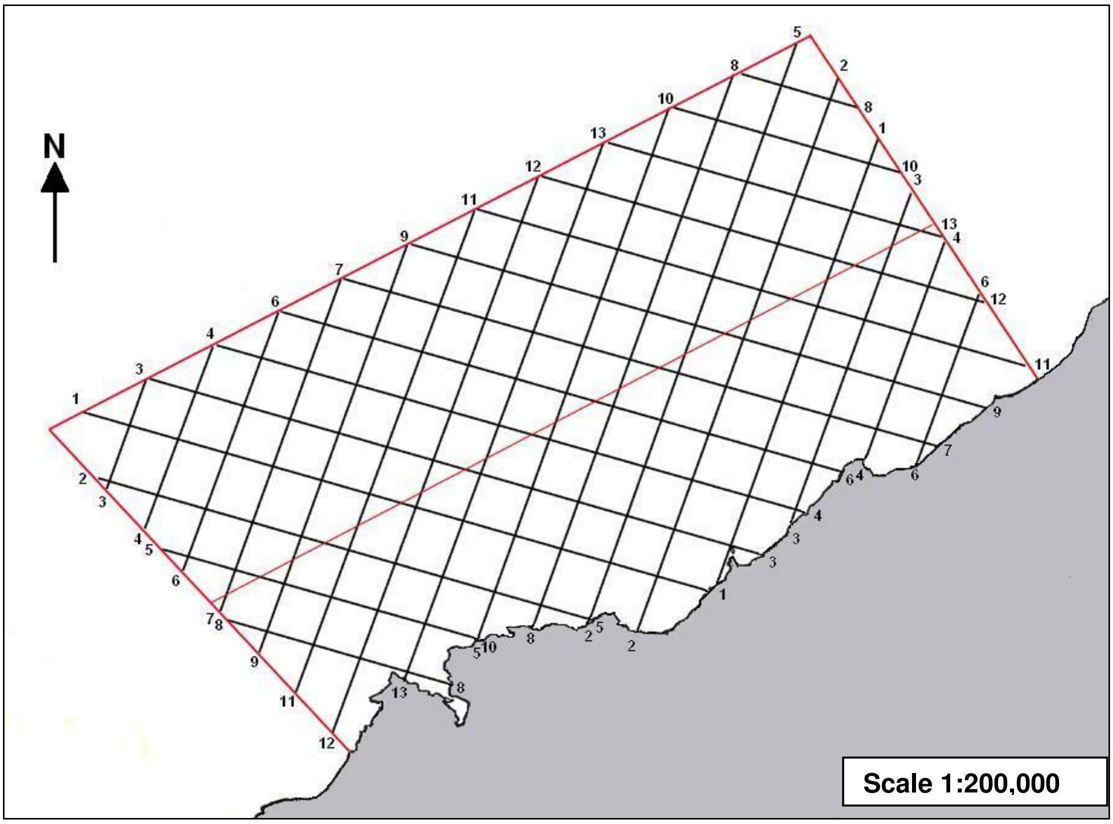

Figure 2.2: The line transect grid of Cardigan Bay SAC, comprised of 13 separate transect lines used in the 2003-2005 surveys aboard *Sulaire* or *Dunbar Castle II.*

All surveys in 2003-2004 were carried out aboard the research vessel *Sulaire,* whereas all 2005 surveys were conducted aboard the *Dunbar Castle II.* Survey protocol was the same aboard both vessels and between years. The research vessels cruised each transect at a speed over the ground of 6-8 knots depending on the state of the tide and any prevailing currents. Observer height above the sea surface was similar aboard both vessels (≈ 3m).

2.3 FIELD METHODS – Ship Protocol

Throughout the study period, there were 4-7 observers aboard the vessel during each research survey. In order to allow dual platform survey techniques to be implemented, 2 separate areas of the vessel were allocated as observation platforms. The primary platform, which contained 2 observers at any one time, was located above the wheelhouse of the vessel. The second platform, known as the independent observer (IO) platform from here on, was located on the deck behind the primary platform (Figure 2.3). This configuration was named the independent observer (IO) configuration and shall be referred to by this name for the rest of this thesis. Observers on the primary platform were separated, both visually and audibly, from the IO platform thus it was assumed that any sightings recorded by the primary platform were independent of any sightings by the IO platform. However, due to restrictions imposed by the size of the survey vessels, it was not possible to isolate the observers on the IO platform from visual cues from the primary platform thus; only one-way independence was achieved between observation platforms. This type of independence is referred to as trial independence (Buckland *et al.* 2004), where the sightings efficiency of only one observation platform is estimated.

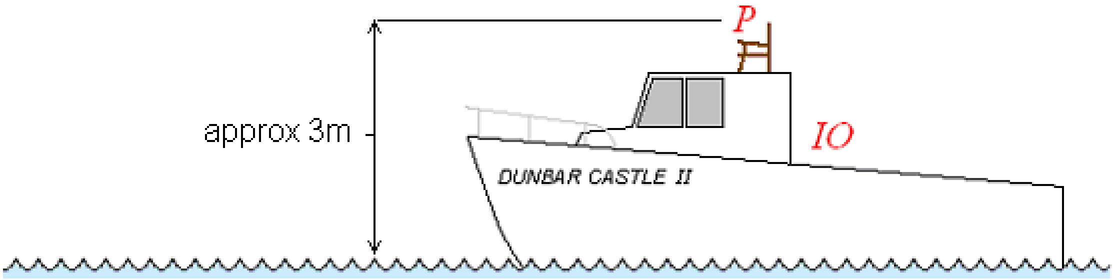

Figure 2.3: Independent observer configuration aboard the survey vessel during line transect surveys. *P*=Primary platform, *IO* = Independent observer platform.

Observers on both observation platforms were changed every hour to allow for rests in between shifts and to reduce bias from fatigue. Observers on both observation platforms scanned the area ahead of ship from the trackline to 90º either side of the vessel continuously for the duration of each hour (Figure 2.4). When an animal was sighted observers estimated the angle to the sighting (°) from the trackline using mounted angle boards, as well as estimating the radial distance to the animal by eye. The time and position of each sighting was recorded using handheld GPS units (GARMIN *e*trex summit). Environmental and behavioural data, including group size, Beaufort sea state, swell height (2005 only), visibility (2005 only), precipitation (2005 only), cue (2005 only), swim direction and movement in response to the vessel (where possible) were recorded at each sighting on sighting forms on both observation platforms (see APPENDIX A). The name of the observer who initially detected each sighting was also recorded to allow for the inclusion of observer experience as a covariate in future analyses (2005 data only). Care was made to minimize visual and audible cues which might alert the other observation platform to a sighting which they may not have detected. Duplicate sightings were established onboard the vessel by communication between platforms after the animal had passed to the stern of the area of water being scanned by the observers. The IO would approach the primary platform and ask if they had detected the animal. The primary observers would convey the details of their last sighting, including the species, time of sighting, position of the animal, radial distance and angle to sighting, from which, the IO would then decide whether it was a duplicate sighting and record it on the IO sightings form (see APPENDIX A).

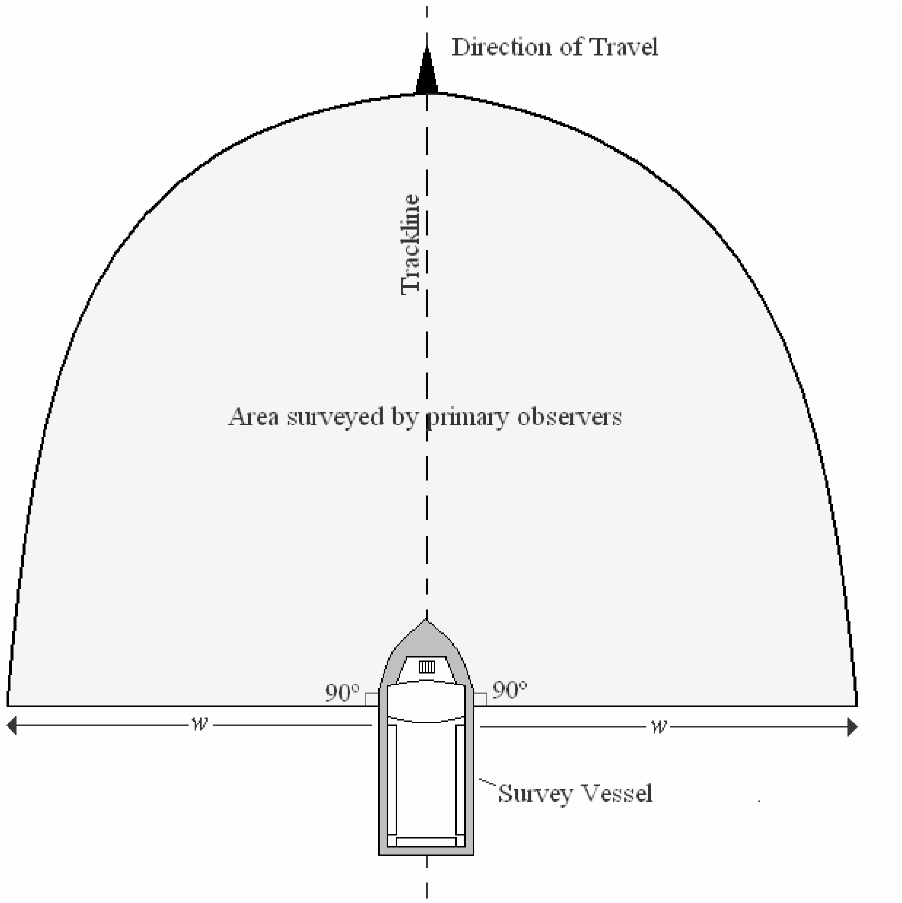

Figure 2.4: Area surveyed 90º either side of the vessel by primary and independent observers during line transect surveys.

Effort type during line transect surveys was split into 4 categories. These were Line Transect (LT), Dedicated Search (DS), Photo ID (ID), and Casual Watch (CW). LT effort type was adopted when the vessel traversed a predetermined transect line during which, observers adopted the independent observer configuration. DS effort type was adopted when the vessel was travelling between the end of one leg/transect line to the beginning of another. Observers also adopted the independent observer configuration during DS effort type. ID effort type was adopted during photoidentification encounters with bottlenose dolphin. During a photo-ID encounter the vessel would leave the transect line to photograph the dolphins and then return back to the exact point from where it left the transect line, after which LT or DS effort type would continue. CW effort type was generally adopted when leaving/returning to port at the beginning and end of surveys, and when environmental conditions deteriorated in a way that made effective LT and DS effort types impossible.

All effort carried out during surveys was recorded on effort forms (see APPENDIX A) by the IO. The effort form contained information regarding the leg number, time and position of each new line of effort, ship speed and course, effort type, Beaufort seastate, swell height (2005 only), visibility, precipitation, and any associated sighting references recorded during that period of effort. Effort began when leaving port and ended upon re-entering port at the end of the survey. A new line of effort was recorded when either the ships course/speed changed significantly, effort type changed, a new leg of a transect began, and when any environmental variables changed. Furthermore, a new line of effort was recorded every 30 minutes as a precaution in case any of the above factors had changed but had not been recorded on the effort form.

2.4 DATA ANALYSIS

2.4.1 Data Handling and Management

All information contained on the sighting and effort forms was entered consecutively into a spreadsheet using MICROSOFT EXCEL XP. The data was then further sorted into separate spreadsheets for sightings data for bottlenose dolphin, harbour porpoise and grey seal. These spreadsheets were formatted into the double observer configuration so that each sighting had 2 rows of data; 1 for the primary observer and 1 for the independent observer. Each sighting in the spreadsheet was assigned 5 mandatory columns titled object, observer, detected, distance, and group size (see APPENDIX B). Object referred to the sighting ID of each individual sighting. Observer refered to the observer that row of data applies to i.e. 1 for primary and 2 for the independent observer. Detected referred to whether or not that sighting was detected (1) or not detected (0) by that observer. The data in the column titled distance contained the perpendicular distance to each sighting and was calculated using the equation $r \sin\theta$, where r is the radial distance to the sighting and $\sin\theta$ is the sine of the angle to the sighting. The column containing group size simply contained the estimated group size of each sighting, taken directly from the sightings form. Additional columns were added for each sighting which contained the values of the covariates to be included in the estimation of $g(0)$. All values for the covariates were taken directly from the sightings forms except for the covariates for observer experience which was calculated after the surveys were completed. Observer experience was split into 3 categories depending on the ability of the observer to detect harbour porpoise compared to the senior observers of the surveys who were already classified as experienced observers (level 3). These categories were: 1 = inexperienced observer (miss most porpoise), 2 = moderately experienced observer (detects some porpoise), and 3 = experienced observer (detect most porpoise). One of the rankings of observer experience was assigned to the observer who initially detected each sighting. Some observers were present over the whole of the survey period in 2005 and thus their level of experience improved throughout the course of the year. To account for this the level of observer experience assigned to individual observers increased in accordance to reduce any bias in the results.

2.4.2 Estimation of g(0)

The formatted spreadsheets were imported into the programme DISTANCE version 5.0 beta for all further analysis.

The Mark-Recapture Distance Sampling (MRDS) engine in DISTANCE 5.0 was used to produce estimates of $g(0)$ for each species. The data was fitted so that $g(0)$ was estimated using the trial observer configuration (primary observer only) and point independence was assumed in accordance with Laake (1999) as it is unlikely that there would be independence between both platforms for sightings at distances greater than 0, as larger groups are more likely to be detected by both platforms. The detection function was fitted with the Mark Recapture (MR) model (equation 1) with a perpendicular distance, group size, sea state, year (2003/2004 only). Year was incorporated into model for 2003/2004 only, as low sample size required these datasets to be combined (see results). Consequently, year was incorporated into the model to account for any heterogeneity in detection between years. The raw data from the 2005 surveys allowed for the incorporation of the additional covariates of swell, cue, and observer experience into the model as well Beaufort sea state and group size. The model with the lowest Akaikes Information Criterion (AIC) was selected as the most reliable estimate for $g(0)$ for that species. Akaikes Information Criterion is a quantitative statistical method of model selection which allows for the analysis of how well the model (in this case the MR model) fits the detection function histogram (Buckland *et al.* 2001). The model for the detection that is the best fit to the actual data results in a reduction in the value of AIC and hence is assumed to be the best fitting model. By incorporating covariates in various combinations into the Equation 1, the model with the lowest AIC value will theoretically be the best fitting model of the detection function, The probability of detection for the best fitting model selected by AIC at distance zero will give an estimate of $g(0)$ for that survey.

The MR model used in programme distance is a logistic model that is written:

$$g_{j|3-j}(\boldsymbol{x},\underline{z}) = \frac{\exp(\beta_0+\beta_1 z_1+\beta_2 z_2+\beta_q z_q)}{1+\exp(\beta_0+\beta_1 z_1+\beta_2 z_2+\beta_q z_q)}$$

Equation 1

where:

$g(x, \underline{z})$ = The probability of sighting an animal at distance x accounting for the covariate $\underline{z}$

exp = is the value of e (2.71828…) to the power of (number) i.e. $e^{(number)}$

j = Observation platform where 1 = primary and 2 = independent

β = The parameter to be estimated

q = The number of covariates

This can be simplified and written as:

$$g(\boldsymbol{x}) = \frac{\exp(\beta \boldsymbol{x})}{[1+\exp(\beta \boldsymbol{x})]}$$

Equation 2

This MR model in its simplest form (Equation 2) is a basic logistical model which forms similar shape to a standard detection function (half bell shape), thus it forms a good basis on which to base a model (Borchers 2005). This is why this approach is used to estimate the detection function at all distances however, Equation 2 does not account for bias from covariates. To account for heterogeneity in detection as a result of variation in covariates such as sea state and group size the model is extended so that:

$$\boldsymbol{g}(\boldsymbol{x},\boldsymbol{z}) = \frac{\exp(\beta_1\boldsymbol{x} + \beta_2\boldsymbol{b} + \beta_3\boldsymbol{s})}{[1 + \exp(\beta_1\boldsymbol{x} + \beta_2\boldsymbol{b} + \beta_3\boldsymbol{s})]} \qquad \text{Equation 3}$$

Where x is the perpendicular distance to the sighting, b is the Beaufort sea state the sighting was detected in, and s is the group size. Thus by adding covariates along with each sighting, the detection function can be estimated (along with the parameters β) using programme DISTANCE, by fitting a line through the probability of detection for all sightings collectively. From here estimates of $g(0)$ can be obtained by using the probability of detection of the detection function at distance zero.

3. RESULTS

3.1 SURVEY AND SIGHTINGS SUMMARY

Line transect surveys of the Cardigan bay SAC were conducted over 3 consecutive years during the summers of 2003-2005. Surveys during 2003 and 2004 were conducted aboard the vessel *Sulaire,* with all surveys in 2005 being conducted aboard the *Dunbar Castle II.* A summary of the surveys effort is available in Table 3.1. A total of 3753.83km of sea within the SAC were surveyed over 3 years on LT or DS effort types. The largest amount of effort was performed in 2005, where 2031.91km of LT and/or DS effort were completed, compared to only 828.93km and 892.99km in 2003 and 2004 respectively. Mean vessel speed was similar across all years, ranging from 7.01-7.46 knots with a mean vessel speed over all 3 years of 7.29 knots.

	Survey Vessel	**LT & DS Effort (km)**	**Mean vessel speed (knots)**
2003	*Sulaire*	828.93	7.46
2004	*Sulaire*	892.99	7.41
2005	*Dunbar Castle II*	2031.91	7.01
TOTAL	n/a	3753.83	

Table 3.1: Effort summary for line transect surveys of Cardigan Bay SAC performed over 3 consecutive years between April and October 2003-2005.

A total of 618 sightings of marine mammals were recorded on LT and DS effort types over the 3 year study period. Of these 618 sightings, 199 were detected by both sets of observers and recorded as duplicate sightings. A summary of the number of sightings for each species, in each year is presented in table 3.2. Table 3.2 indicates that harbour porpoise (HP) were the most commonly sighted marine mammal, with 266 of all of the sightings recorded over the 3 year period were, of which 80 were duplicate sightings. Grey seal (GRS) were the second most commonly sighted animal, with a total of 196 sightings (58 duplicate sightings) over the 3 year period. Bottlenose dolphins (BND) were the least commonly sighted marine mammal in the Cardigan Bay SAC, with a total of 156 sightings

(61 duplicate sightings) over the 3 years. However, the proportion of duplicate sightings was highest for bottlenose dolphins at 0.391 of all sightings compared to 0.296 and 0.301 for grey seal and harbour porpoise respectively.

	BND	**GRS**	**HP**	**TOTAL**	**Proportion of duplicates**
	No. of sightings (of which duplicates)	No. of sightings (of which duplicates)	No. of sightings (of which duplicates)		
2003	47(8)	55(9)	67(14)	**169 (31)**	**0.183**
2004	25 (7)	74 (17)	80 (26)	**179 (50)**	**0.279**
2005	84 (46)	67 (32)	119 (40)	**270 (118)**	**0.437**
TOTAL	**156 (61)**	**196 (58)**	**266 (80)**	**618 (199)**	
Proportion of duplicates	**0.391**	**0.296**	**0.301**		

Table 3.2: Sightings summary showing the number of sightings, and the number of these sightings that are duplicate sightings in brackets, of bottlenose dolphin (BND), grey seal (GRS), and harbour porpoise (HP) detected during line transect surveys of Cardigan Bay SAC over 3 consecutive summers between April to October 2003-2005.

As previously reported, the surveys in 2005 completed the largest amount of survey effort (km) out of all of the 3 years. It is therefore unsurprising that 2005 yielded the highest number of sightings (270) compared 179 and 169 in 2004 and 2003 respectively. Furthermore the proportion of duplicate sightings in 2005 increased to 0.437 compared to 0.279 and 0.183 in 2004 and 2003 respectively, suggesting that there may be an increase in the emphasis placed on the IO, or an increase in the awareness of the IO platform in 2005.

Duplicate sightings and independent observer non-duplicate (IOND) sightings form the basis of all estimates surrounding $g(0)$ when using mark recapture techniques. Due to the low number of duplicate sightings recorded in the surveys from 2003 and 2004 (see table 3.2) it proved to be very difficult to interpret any significant findings from such a small sample size (discussed in section 3.3) thus it was necessary to combine both sets of data to increase the sample size and statistical power of the results. This was possible as both the 2003 and 2004 surveys were conducted aboard the same vessel, using the same senior observers, using the same techniques, in the same study area (Cañadas *et al.* 2005). From this point onwards the 2003 and 2004 data sets are combined and analysed as one complete data set referred at as the 2003/04 dataset (unless otherwise stated).

	Mean sea state (SD)	**Mean Group Size (SD)**		
		BND	**GRS**	**HP**
2003/04	1.07 (0.72)	3.82 (2.93)	1.35 (1.12)	1.74 (1.11)
2005	1.50 (0.88)	2.76 (1.99)	1.00 (0.00)	1.75 (1.35)
t-test *p-value*	**<0.001**	**0.013**	**N/A**	**0.952**

Table 3.3: Comparative assessment of the mean (and standard deviation) Beaufort sea state and group size of marine mammals encountered during line transect surveys of Cardigan Bay SAC during the line transect of 2003/04 and 2005.

Mean Beaufort sea state was significantly higher (t = 1.50, p = <0.001) in the 2005 surveys at 1.50 (SD = 0.88), compared to 1.07 (SD = 0.72) in the 2003/04 surveys (Table 3.3). Mean group size of bottlenose dolphins was significantly larger (t = 3.82, p = 0.013), and displayed larger variation around the mean, in the 2003/04 than in the 2005 surveys. In contrast, mean group sizes of harbour porpoise were very similar between years, with mean group sizes of 1.74 (SD = 1.11) and 1.75 (SD = 1.35) in the 2003/04 and 2005 surveys respectively. Statistical comparison of mean grey seal group sizes was not possible as only solitary seals were sighted in the 2005 surveys.

3.2 PERPENDICULAR SIGHTINGS DISTRIBUTIONS

The perpendicular sightings distribution of sightings by the primary and independent observer (IO) platforms, for each species of marine mammal with each year, are displayed in Figures 3.1, 3.2, and 3.3. In accordance with Buckland *et al.* (2001) up to 10% of the data was right-truncated to the nearest 50m order to remove outlying sightings that can affect the shape of the detection function and corresponding density and abundance estimates.

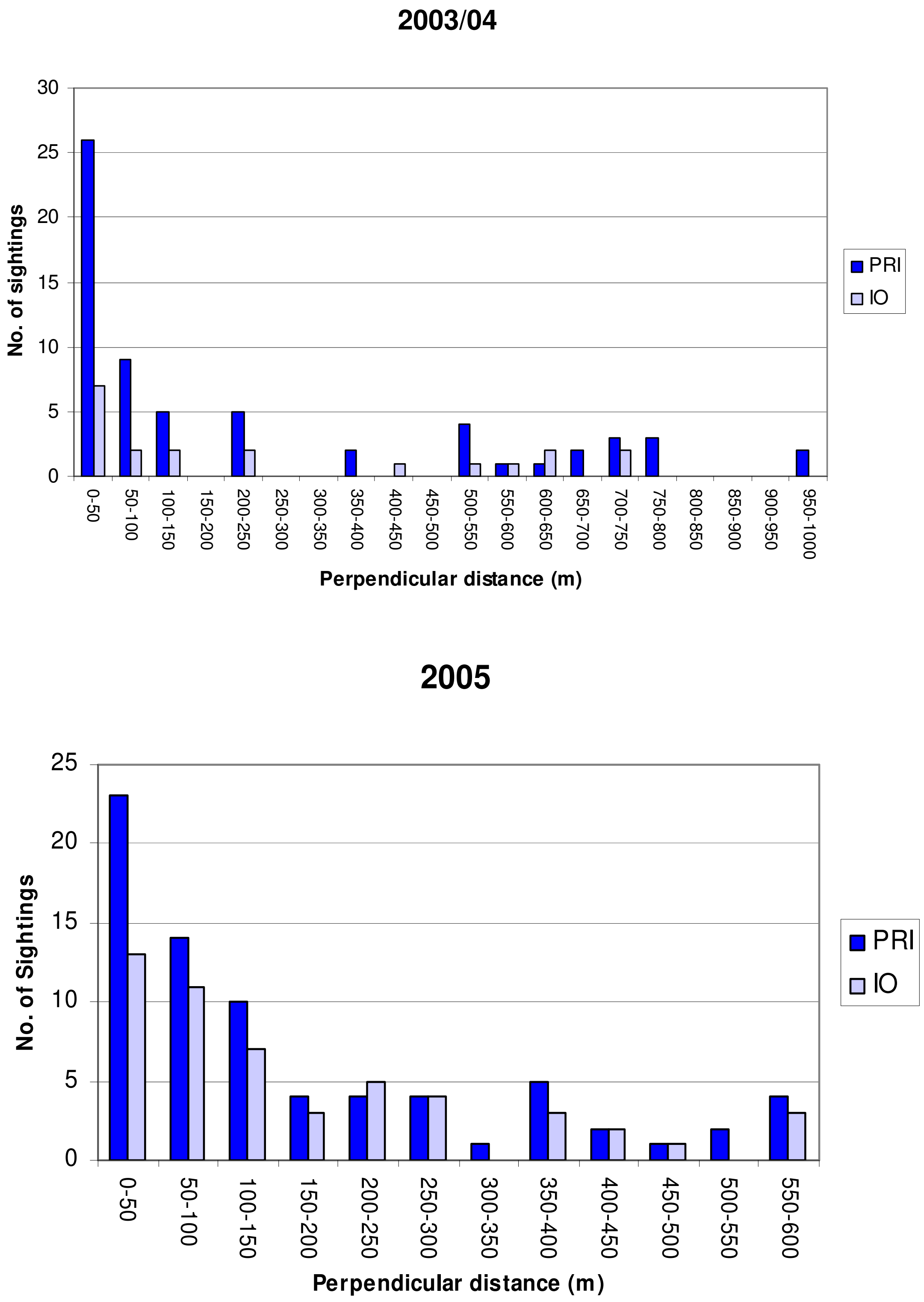

Figure 3.1: Perpendicular sightings distribution of bottlenose dolphin sightings recorded by the primary (PRI) and independent observer (IO) platforms during line transect surveys of Cardigan Bay SAC in 2003/04 and 2005.

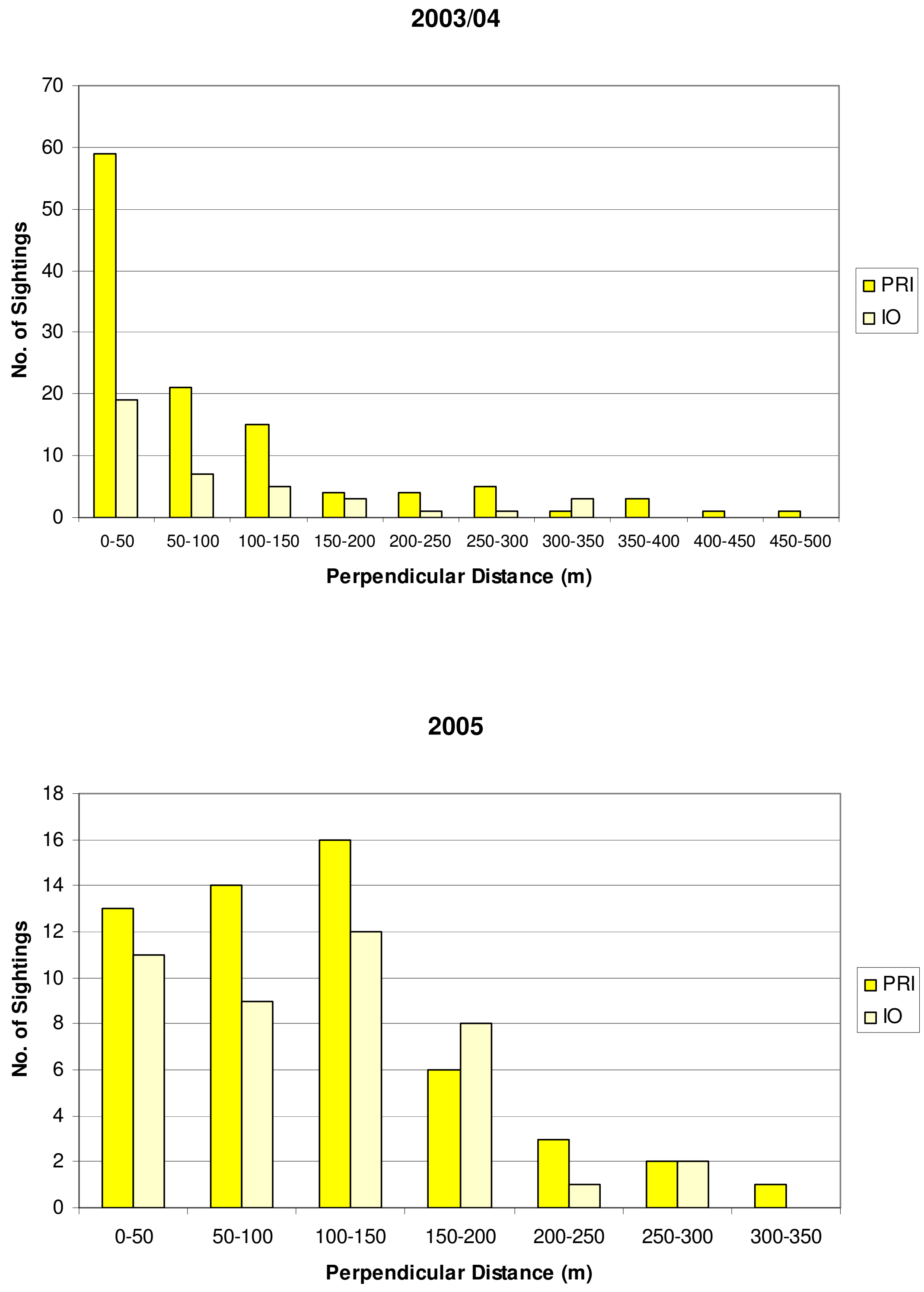

Figure 3.2: Perpendicular sightings distribution of grey seal sightings recorded by the primary (PRI) and independent observer (IO) platforms during line transect surveys of Cardigan Bay SAC in 2003/04 and 2005.

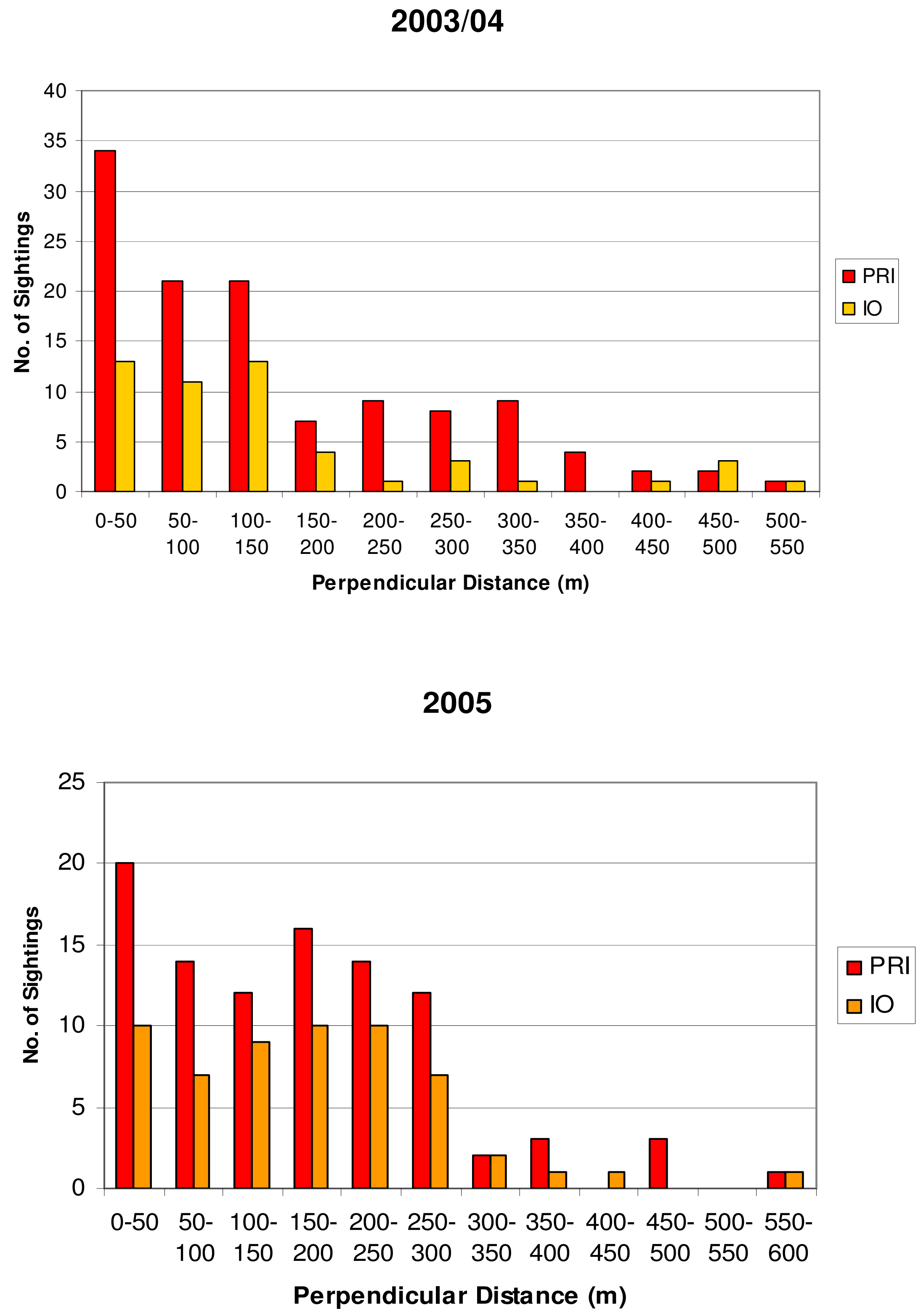

Figure 3.3: Perpendicular sightings distribution of harbour porpoise sightings recorded by the primary (PRI) and independent observer (IO) platforms during line transect surveys of Cardigan Bay SAC in 2003/04 and 2005.

3.2.1 Bottlenose Dolphin

The sightings of bottlenose dolphins were right truncated at 1000m in the 2003/04 surveys losing 3.8 % of the data. In contrast, the bottlenose dolphin sightings from the 2005 surveys were truncated 600m (3.7% data loss). Figure 3.1 highlights the lack of bottlenose dolphin sightings in the combined 2003/04 surveys, with very few sightings beyond 50m from the trackline compared to the 2005 surveys. The perpendicular sighting distribution for the 2003/04 data shows that sightings by the primary observer are highly concentrated on or close to the trackline, and rapidly decreased as the perpendicular distance from the trackline increased. Sightings by the IO also peaked in the 0-50m distance interval, although there were only 7 sightings in this interval. This low number of bottlenose dolphin sightings by the IO in the 2003/04 surveys suggests that a low number of duplicate sightings were recorded, and hence estimates of $g(0)$ for bottlenose dolphin in the 2003/04 surveys may be biased by low sample size, despite combining the two surveys.

The perpendicular sightings distribution for bottlenose dolphin sightings in the 2005 surveys displayed a steady decrease in the number of sightings by both platforms as the perpendicular distance increased. There proportion of IO sightings in relation to primary observer sightings, was also far higher in the 2005 data than in the 2003/04 data suggesting that the number of duplicate sightings at all distances was greatly improved. Both the primary and IO platform recorded the highest frequency of sightings in the 0-50m distance interval, with the primary platform recording a higher number of sightings than the IO platform in each distance interval, with the exception of the 200-250m interval where the IO platform detected 5 groups compared to only 4 by the primary platform.

3.2.2 Grey Seal

The perpendicular sightings distributions for grey seal in figure 3.2 displayed highly contrasting distributions between the 2003/04 and 2005 datasets. The 2003/04 data was right truncated at 500m (2.3% data loss) compared 350m (no data loss) in the 2005 surveys. The sightings of grey seal in the 2003/04 dataset displayed a high degree spiking of sightings on or close to the trackline, followed by a rapid decrease in the number of sightings per distance interval as the perpendicular distance from the trackline increased. Both platforms recorded the highest number of sightings in the 0-50m distance interval (59 by the primary platform, 19 by the IO platform). Within 150m of the trackline, the IO platform only detected ⅓ of the number of grey seals that were detected by the primary platform in each distance interval.

The 2005 perpendicular sightings distribution for grey seal indicated that both platforms recorded the highest number of sightings (16 by the primary platform, 12 by the IO platform) in the 100-150m distance interval, with fewer sightings on or close to the trackline. Beyond 150m, sightings by both platforms rapidly decreased out to the truncation distance. The ratio of the number of IO sighting to the number of primary platform sightings per distance interval, was far higher in the 2005 surveys compared to the 2003/04 surveys. The IO platform consistently detected more than ½ the number of the sightings that the primary platform recorded in each distance interval, with the IO platform logging 8 sightings in the150-200m interval compared to only 6 by the primary platform.

3.2.3 Harbour Porpoise

The harbour porpoise sightings data in figure 3.3 was truncated at 550m (4.7% data loss) in the 2003/04 surveys, and at 600m (0.8% data loss) in the 2005 surveys. The perpendicular sightings distribution for the 2003/04 dataset indicated that the primary platform detected the highest number of harbour porpoise (34 sightings) in the 0-50m distance interval. In comparison the IO platform recorded the highest number of sighting (13) in both the 0-50m and 100-150m distance intervals. The number of sightings by both platforms notably decreased beyond 150m from the trackline, with few sightings by the IO platform beyond this distance.

The ratio of sightings of harbour porpoise by the IO platform in relation to primary platform was consistently higher in each distance interval in the 2005 dataset, compared to the 2003/04 data. The perpendicular sightings distribution of the 2005 dataset displayed a broad distribution, with a higher proportion of sightings beyond 150m than in the 2003/04 data. The primary platform recorded the highest number of sightings (20) in the 0-50m interval, whereas the IO platform recorded 10 sightings in the 0-50m, 150-200m, and 200-250m distance intervals. There was a broad secondary spiking of sightings recorded by both platforms (particularly by the primary platform) between 100-300m from the trackline suggesting that some responsive movement in relation to the vessel may have occurred.

3.3 PRELIMINARY ESTIMATION OF *G*(0)

Preliminary estimates of $g(0)$ were obtained through a simple analysis of the proportion of IO sightings on or near to the trackline, that were duplicated by the primary observer. 3 distances (60m, 80m and 100m) from the trackline were used to define the boundary within which, all sightings would be classed as being on the trackline. All IO sightings within these 3 distance intervals were classified as one of two types of sightings. 1) Duplicates sightings (D), if the sighting was also recorded by the primary platform or, 2) independent observer non-duplicate sightings (IOND), if the sighting was not recorded by the primary platform.

The basic estimate of $g(0)$ for bottlenose dolphin in table 3.4 varied with each year, and with each trackline cut of distance. Estimates of $g(0)$ ranged from 0.667-1.000 ($\bar{x}$ = 0.778, SE = 0.111) in 2003, 0.714-1.000 ($\bar{x}$ = 0.809, SE = 0.095) in 2003/2004 combined, and 0.957-1.000 ($\bar{x}$ = 0.972, SE = 0.014) in 2005. In the 2004 surveys, $g(0)$ was consistently estimated to be 1.000 in all 3 cut off distances however, there was only 1 duplicate sighting on the trackline in the whole dataset. The low number of sightings of bottlenose dolphin on the trackline in the 2003 and 2004 datasets supports the reasoning to combine the datasets in order to increase the sample size. Nonetheless, even in the combined 2003/04 dataset, the duplicate sample size was still very low, which caused a large amount of variation (SE = 0.095) around the mean estimate of $g(0)$ (0.809). The initial estimates of $g(0)$ for bottlenose dolphin from the 2005 surveys appeared to be 16% higher than that of the combined 2003/04 surveys with far less variation around the mean (SE = 0.014), suggesting that the sightings efficiency of observers in 2005 was higher than that of 2003/2004.

2003

		100m		80m		60m		$\bar{x}$
BND	D	4	0.667	4	0.667	4	1.000	**0.778**
	IOND	2		2		0		
GRS	D	9	0.818	9	0.900	9	0.900	**0.873**
	IOND	2		1		1		
HP	D	8	0.727	7	0.875	6	0.857	**0.853**
	IOND	3		1		1		

2004

		100m		80m		60m		$\bar{x}$
BND	D	1	1.000	1	1.000	1	1.000	**1.000**
	IOND	0		0		0		
GRS	D	13	0.765	10	0.712	9	0.750	**0.742**
	IOND	4		4		3		
HP	D	13	0.722	11	0.688	6	0.600	**0.670**
	IOND	5		5		4		

2003/04 combined

		100m		80m		60m		$\bar{x}$
BND	D	5	0.714	5	0.714	5	1.000	**0.809**
	IOND	2		2		0		
GRS	D	22	0.786	19	0.792	18	0.818	**0.799**
	IOND	6		5		4		
HP	D	21	0.724	18	0.750	12	0.706	**0.727**
	IOND	8		6		5		

2005

		100m		80m		60m		$\bar{x}$
BND	D	23	0.958	22	0.957	16	1.000	**0.972**
	IOND	1		1		0		
GRS	D	18	0.900	16	0.941	13	0.929	**0.923**
	IOND	2		1		1		
HP	D	16	0.842	15	0.833	9	0.750	**0.808**
	IOND	3		3		3		

Table 3.4: Basic estimate of *g*(0) for bottlenose dolphin (BND), grey seal (GRS), and harbour porpoise (HP) in Cardigan Bay SAC using 3 perpendicular distances from the trackline within which all sightings are classed as being on the trackline. Estimates are derived by investigating the proportion of independent observer (IO) sightings that are duplicate (D) and non duplicate (IOND) sightings within the 3 given distances from the trackline.

Estimates of *g*(0) for grey seal tended to be more consistent than bottlenose dolphin estimates within each year, but displayed larger variation between years. Estimates of *g*(0) for grey seal ranged from 0.818-0.900 ($\bar{x}$ = 0.823, SE = 0.027) in the 2003, 0.712-0.765 ($\bar{x}$ = 0.742, SE = 0.016) in 2004, 0.786-0.818 ($\bar{x}$ = 0.799, SE = 0.010) in 2003/2004 combined, and 0.900-0.941 ($\bar{x}$ = 0.923, SE = 0.012) in the 2005. These results suggest that approximately 80% of all grey seal on the trackline were detected by the primary observers in the 2003/2004 surveys. However, there appears to have been a 12% increase in the sightings efficiency of the primary observers in the 2005 surveys.

Estimates of *g*(0) for harbour porpoise in table 3.4, indicate that they were consistently least detectable marine mammal on the trackline in each year of the surveys. Estimates of *g*(0) for harbour porpoise ranged from 0.727-0.875 ($\bar{x}$ = 0.820, SE = 0.014) in 2003, 0.600-0.722 ($\bar{x}$ = 0.670, SE = 0.036) in 2004, 0.706-0.750 ($\bar{x}$ = 0.727, SE = 0.13) in 2004/2004 combined, and 0.750-0.833 ($\bar{x}$ = 0.808, SE = 0.029) in 2005. These results suggest that approximately 73% of all harbour porpoise on the trackline were detected by the primary observers in the 2003/2004 surveys, and the trackline sightings efficiency of the primary observers increased 81% in 2005. Mean estimates of *g*(0) for harbour porpoise, showed the least amount of variation between years, out of the 3 species of marine mammal tested.

3.4 ESTIMATION OF *G*(0) USING DISTANCE 5.0

Various combinations of the covariates that are described in the methods were incorporated into the mark-recapture (MR) model in the mark-recapture distance sampling (MRDS) engine in programme DISTANCE 5.0 Covariates were included by incorporating different commands into the model definition. The covariates were assigned abbreviated command names (Table 3.5) and shall be referred to by these command names in all the following tables presented in this study. The covariates were written into the model definition in 2 ways. Covariates were written into the model definition individually, by separating each command name with a + symbol i.e. distance + size + sea. However, the interaction between 2 covariates could be included by separating each covariate by a * symbol. For example, if the interaction between sea state and swell were to be included then sea*swell would be written into the formula, which would translate to sea + swell + sea:swell, where sea:swell is the interaction component of the 2 covariates. These commands are included in the tables 3.6-3.12 below.

Original Name	Command Name
Perpendicular distance	distance
Group size	size
Beaufort sea state	sea
Year (2003-2004 only)	year
Swell (2005 only)	swell
Observer experience (2005 only)	exp
Cue (2005 only)	cue

Table 3.5: The command names given to each covariate when incorporated into the model definition function in programme DISTANCE 5.0.

3.4.1 ESTIMATION OF G(0) FOR BOTTLENOSE DOLPHIN

3.4.1.1 The 2003/04 Surveys

The qq-plot (see APPENDIX B) for MR model fitted to the bottlenose dolphin data shows that the fitted cumulative distribution function (cdf), plotted against the empirical distribution function (edf) displayed large variations from the expected linear distribution (dotted line). The test statistics echo this with the total chi-square value of $\chi = 26.367$, (p =<0.001) and Kolmogorov-Smirnov test statistic of 0.387 ($p < 0.001$). This may well be due to the large number of primary sightings on the trackline, followed by the rapid decrease in the number of sightings in the 298-498m interval in figure 3.4. This indicates that any estimates of density and abundance for bottlenose dolphin from the 2003/04 using the MR model were likely to be biased. However, the MRDS engine in DISTANCE 5.0 requires a distance sampling (DS) component to influence the shape of the curve, and a MR component to estimate the intercept of the curve, i.e. estimate the detection probability at distance = 0 (Buckland *et al.* 2004). Thus, the MR component is needed to estimate $g(0)$ and the chi-square test statistic for the MR component of the model indicated that the MR component of the model was a suitably good fit to the data ($\chi = 0.688$, df = 1, $p = 0.407$).

Estimates of $g(0)$ for bottlenose dolphin produced by the MR model in programme DISTANCE (Table 3.6) varied from 0.612 – 0.750 ($\bar{x} = 0.677$, SE = 0.138), indicating that approximately 61 – 75% of bottlenose dolphin on the trackline were detected by the primary observers during the 2003-2004 surveys. The model selected by the lowest AIC as the best fitting model was the MR model which incorporated perpendicular distance and group size as covariates (AIC = 861.76). This model produced an estimate of $g(0)$ of 0.705 indicating that 71% of all bottlenose dolphin on or near to the trackline were detected by the primary observers.

Model definition	No. of Parameters	ΔAIC	AIC	*g*(0)
MR distance + size	4	0.00	861.76	0.705
Peterson	2	0.32	862.08	0.750
MR distance	3	1.23	862.99	0.648
MR distance + size + year	5	1.93	863.69	0.697
MR distance + size + sea	5	2.00	863.76	0.706
MR distance + year	4	2.39	864.15	0.612
MR distance + size*sea	6	3.14	864.90	0.730
MR distance + sea	4	3.22	864.98	0.647
MR distance + size*year	6	3.82	865.58	0.714
MR distance + size + sea + year	6	3.93	865.69	0.700
MR distance + sea + year	5	4.39	866.19	0.612
MR distance + sea*year	6	4.59	866.25	0.622

Table 3.6: The model definition formula, number of parameters, Akaike Information Criterion (AIC) value, and estimated $g(0)$ for the fitted detection function for bottlenose dolphin data collected in line transect surveys of Cardigan Bay SAC in 2003/04.

Figure 3.4 displays the perpendicular sightings distribution for sightings by the primary observer overlaid with the MR model (solid line) that incorporated perpendicular distance and group size as covariates. The dots represent the individual sighting probability of each sighting when distance and group size are taken into account.

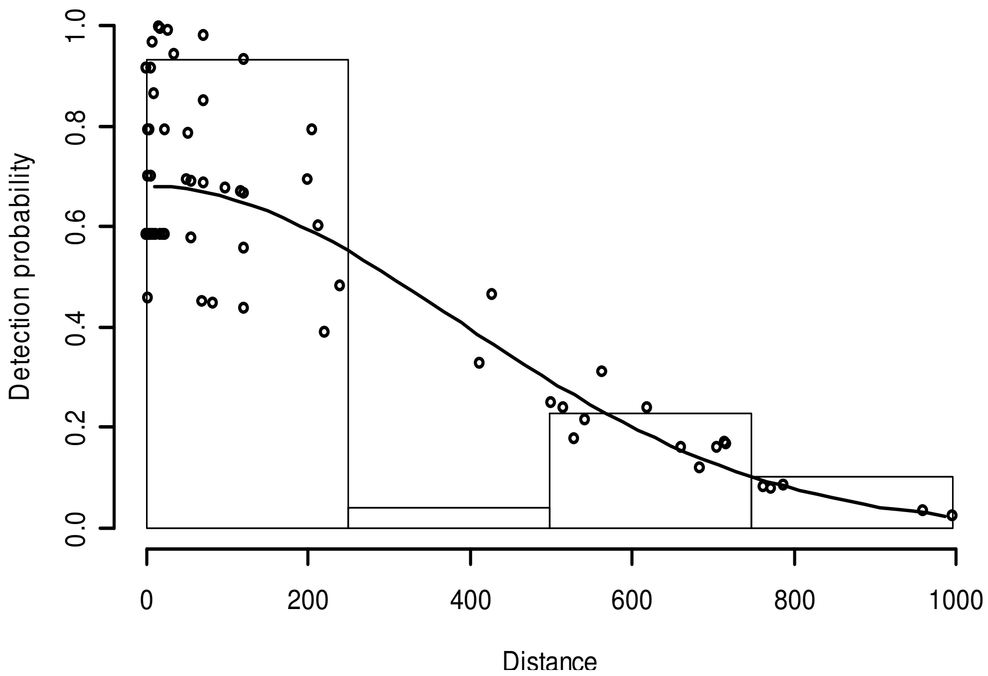

Figure 3.4: Detection function for bottlenose dolphin sightings (truncated at 1000m) recorded by the primary observers during the 2003/04 surveys of Cardigan Bay SAC. The solid line shows detection function of the Mark-Recapture (MR) model that incorporates perpendicular distance and group size as covariates. The dots indicate the individual detection probability of each sighting.

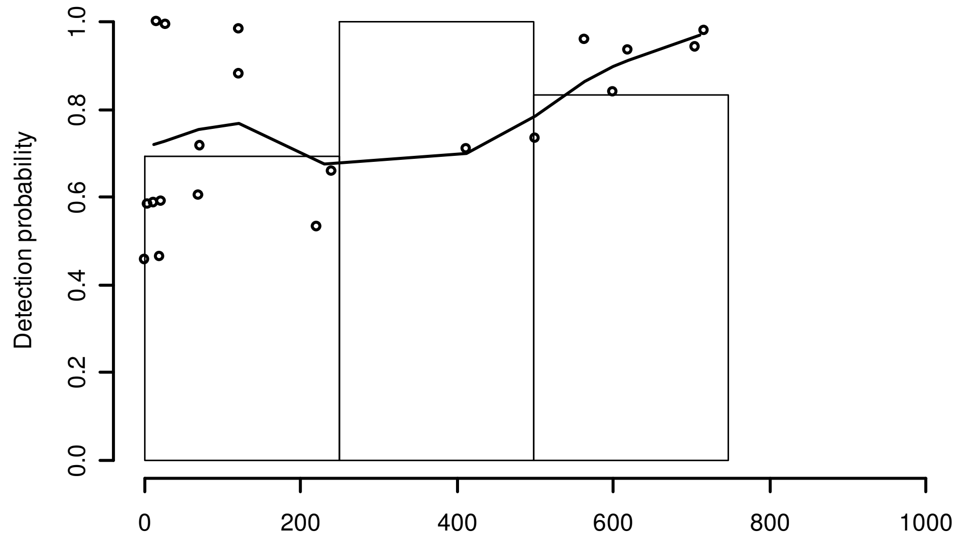

Figure 3.5: Histogram showing the probability of detection of duplicate sightings of bottlenose dolphin with perpendicular distance (m) recorded during the 2003/04 surveys of Cardigan Bay SAC. The solid line shows the duplicate detection function of the Mark-Recapture (MR) model that incorporates perpendicular distance and group size as covariates. The dots indicate the individual detection probability of each sighting

The number of sightings by the primary observer in figure 3.4 drops off dramatically as the distance from the trackline increases whereas, in figure 3.5 the proportion of duplicate sightings increased as the distance from the trackline increases. This suggests that there is some form of unmodelled heterogeneity affecting the probability of detection of duplicate sightings as the distance from the trackline increases. There is also a severe spiking of sightings by the primary observer on or near to trackline indicating that there may have been some responsive movement of bottlenose dolphins towards the trackline that would bias any estimates of *g*(0).

	Coefficients	SE
Intercept	-0.6762	1.1414
Perpendicular distance	0.0014	0.0030
Group size	0.5056	0.5008

Table 3.7: The conditional detection function parameters, and their SE, for the explanatory variables in best fitting model of the detection function (selected by AIC), for bottlenose dolphin sightings in the 2003/04 surveys of Cardigan Bay SAC.

The fitted model (dotted line) in figure 3.5 indicated that when perpendicular distance and group size were included in the model the probability of detection of duplicate sightings increased as distance from the trackline increased. The conditional detection function parameter for group size in table 3.7 produced a value with a positive sign indicating that as group size increased, the likelihood of detection increased. Similarly the parameter for perpendicular distance has a much lower positive value. The low value of the parameter for perpendicular distance indicated, rather unusually, that as the distance from the trackline increased the probability of detection increased. These factor clearly have the potential to bias estimates of *g*(0)

3.4.1.2 Bottlenose dolphin - The 2005 surveys

The qq-plot (see APPENDIX B) figure 3.6 both suggested that the MR model was a relatively poor fit to the bottlenose dolphin data from the 2005 surveys. The total chi-square test statistic ($\chi = 32.965$, $p < 0.001$, 6 df) and the Kolgomorov-Smirnov test statistic (0.221, $p = 0.002$) supported this. This was most probably attributed to the severe spiking at near distance zero followed by a low detection probability in the 84-169, 169-253, and 253-338m bins. However, the MR component chi-square statistic ($\chi = 3.538$, 1df, $p = 0.06$) suggested that any estimates of $g(0)$ using this model were still valid (although they should be treated with caution), but abundance and density estimates would be biased.

Model definition	**No. of Parameters**	**ΔAIC**	**AIC**	***g*(0)**
MR dist+size+exp+sea	7	0.00	942.77	0.941
MR dist+size	4	0.20	942.97	0.925
MR dist+size+exp+sea+cue	8	0.53	943.30	0.953
MR dist+size+exp	6	0.82	943.59	0.930
MR dist+size+exp+sea+swell	8	0.93	943.70	0.949
MR dist+size+sea	5	0.94	943.71	0.930
MR dist+size+swell	5	1.19	943.96	0.928
MR dist+size+cue	5	1.47	944.24	0.932
MR dist+size+sea+cue	6	2.22	944.99	0.936
MR dist+size+sea+swell	6	2.27	945.04	0.932
MR dist+size+sea+swell+cue +exp	9	2.52	945.29	0.953
MR dist+size+sea+swell+cue	7	4.09	946.86	0.935
MR dist+size+sea (FACT)	7	4.54	947.31	0.927
Peterson	2	5.71	948.48	0.868
MR dist+exp	5	5.80	948.57	0.923
MR dist	3	6.99	949.76	0.901
MR dist+ cue	4	8.86	951.63	0.907
MR dist+sea	4	8.88	951.65	0.905
MR dist+swell	4	8.90	951.67	0.904
MR dist+sea:swell	6	9.86	952.63	0.907

Table 3.8: The model definition formula, number of parameters, Akaike Information Criterion (AIC) value, and estimated $g(0)$ for the fitted detection function for bottlenose dolphin data collected in line transect surveys of Cardigan Bay SAC in 2005.

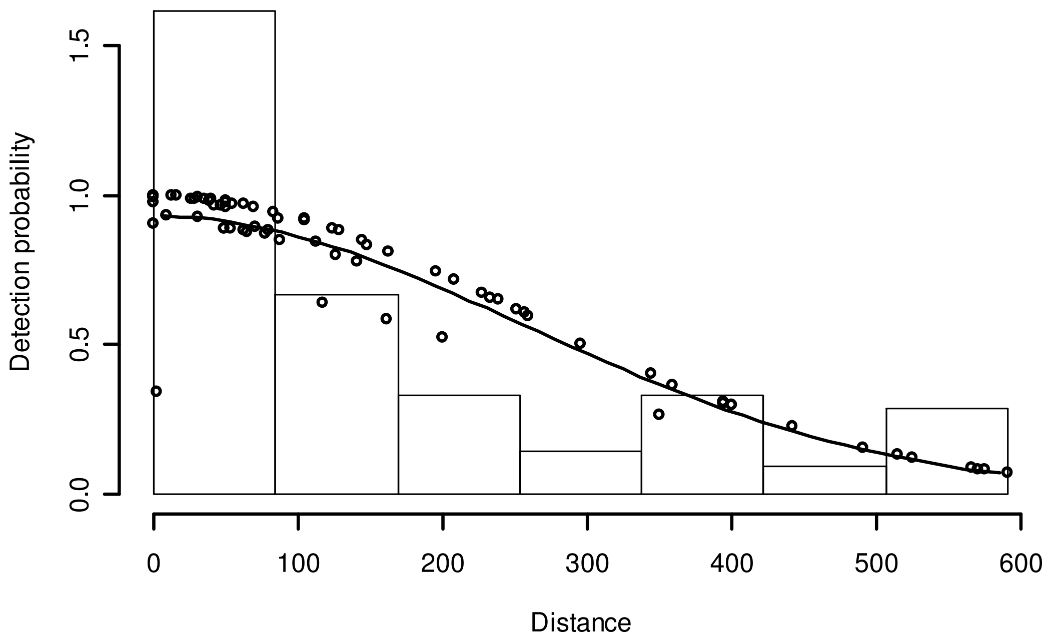

Figure 3.6: fitted detection function of bottlenose dolphin sightings (truncated at 600m) recorded by the primary observers during the 2005 surveys of Cardigan Bay SAC. The solid line shows detection function of the Mark-Recapture (MR) model that incorporates perpendicular distance, group size, Beaufort sea state, and observer experience as covariates. The dots indicate the individual detection probability of each sighting.

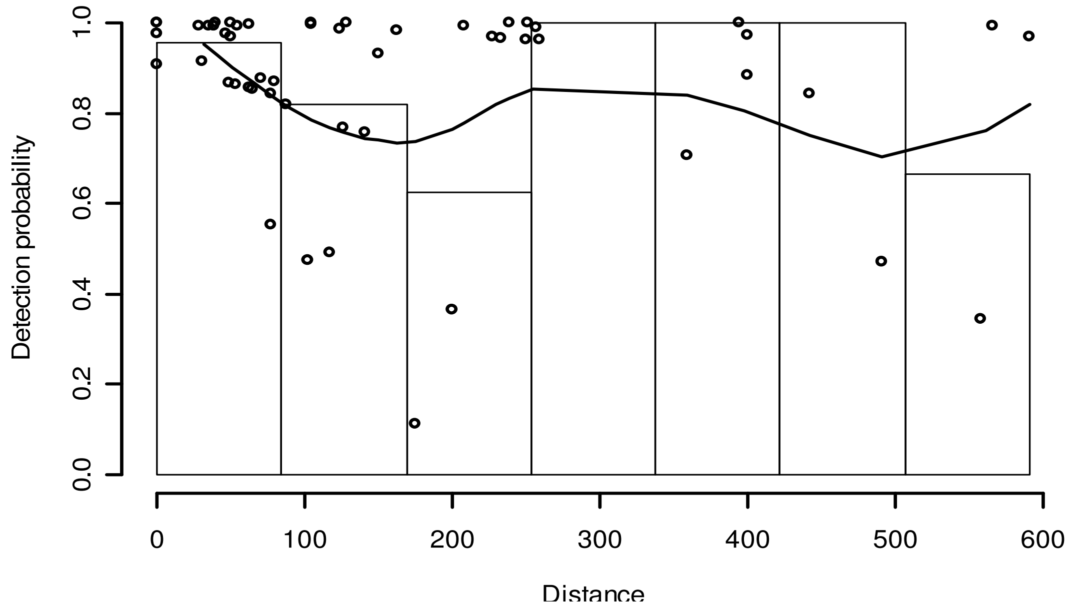

Figure 3.7: Histogram showing the probability of detection of duplicate sightings with perpendicular distance (m) of bottlenose dolphin recorded during the 2005 surveys of Cardigan Bay SAC. The solid line shows duplicate detection function of the Mark-Recapture (MR) model that incorporates perpendicular distance, group size, Beaufort sea state, and observer experience as covariates. The dots indicate the individual detection probability of each sighting.

The range of estimates for *g*(0), for bottlenose dolphin were far higher in the 2005 surveys than in the 2003/04 surveys. Estimates ranged from 0.868-0.953 ($\bar{x}$ = 0.720, SE = 0.004) indicating that the primary observers detected 87-95% of all bottlenose dolphin on the trackline compared to only 61-75% in 2003-2004. The MR model selected by AIC as the best fitting model to the data was the model that incorporated perpendicular distance, group size, observer experience, and Beaufort sea state as covariates (AIC = 942.77).

Figure 3.6 indicated that there was a severe spiking of sightings close to the trackline, suggesting that there may have been some responsive movement towards the vessel which would positively bias any estimates of *g*(0). However, figure 3.7 indicated that there appeared to be no real trend in the probability of detection of duplicate sightings out to the truncation distance. On consultation of table 3.9 it became clear that, despite a general decrease in the probability of detection with increasing perpendicular distance, the positive sign for the conditional detection function coefficient for group size and observer experience, suggested that the larger the group size and the more experienced the observer is, the more likely the animal(s) bottlenose dolphin are detected. Unusually, the sign for the conditional detection function coefficient for Beaufort sea state was positive indicating that bottlenose dolphin were more detectable in higher sea states than they were in calmer conditions.

	Coefficient	**SE**
Intercept	-3.5220	2.8744
Perpendicular distance	-0.0080	0.0040
Groups size	1.4844	0.6694
Observer experience	2.7878	2.0607
Beaufort sea state	1.5604	1.0361

Table 3.9: The conditional detection function parameters, and their SE, for the explanatory variables in best fitting model of the detection function (selected by AIC), for bottlenose dolphin sightings in the 2005 surveys of Cardigan Bay SAC

3.4.2 GREY SEAL

3.4.2.1 Grey seal – The 2003/04 surveys

The qq-plot for the fitted cdf against the edf (APPENDIX B) shows that the total MR model was a poor fit to the data. This was confirmed by the total chi-square ($\chi = 27.625$, $p < 0.001$, 6 df) and Kolmogorov-Smirnov (0.234, $p =$,0.001) test statistics. This poor fit may well have been due to the large number of sightings of grey seal on or near to the trackline, followed by a low number of sightings in the 200-300m, and 300-400m intervals (Figure 3.8). However, the chi-square value for the MR component ($\chi = 3.144$, df = 3, $p = 0.370$) suggested that the MR component fitted the data and that any estimates of $g(0)$ were valid.

A variety of combinations of covariates were incorporated into the MR model (Table 3.10), and the model selected by AIC as the best fitting to the data was the MR model with perpendicular distance as the sole covariate (AIC = 1330.51). Estimates of $g(0)$ for each model ranged from 0.667-0.831 ($\bar{x}$ = 0.806, SE = 0.012), which indicated that approximately 67-83% of all grey seal on or close to the trackline were detected by the primary observes during the 2003-2004 surveys.

Model definition	**No. of Parameters**	**ΔAIC**	**AIC**	***g*(0)**
MR distance	3	0.00	1330.51	0.815
MR distance + size	4	0.13	1330.64	0.823
MR distance + year	4	1.95	1332.46	0.811
MR distance + size + sea	5	1.98	1332.49	0.829
MR distance + sea	4	2.00	1332.51	0.815
Peterson	2	2.09	1332.60	0.667
MR distance + size + year	5	2.13	1332.64	0.823
MR distance + size*year	6	2.30	1332.81	0.810
MR distance + sea*year	6	2.57	1333.08	0.811
MR distance + size*sea	6	2.76	1333.27	0.828
MR distance + sea + year	5	3.95	1334.46	0.811
MR distance + size + sea + year	6	3.97	1334.48	0.831

Table 3.10: The model definition formula, number of parameters, Akaike Information Criterion (AIC) value, and estimated $g(0)$ for the fitted detection function for grey seal data collected in line transect surveys of Cardigan Bay SAC in 2003/04.

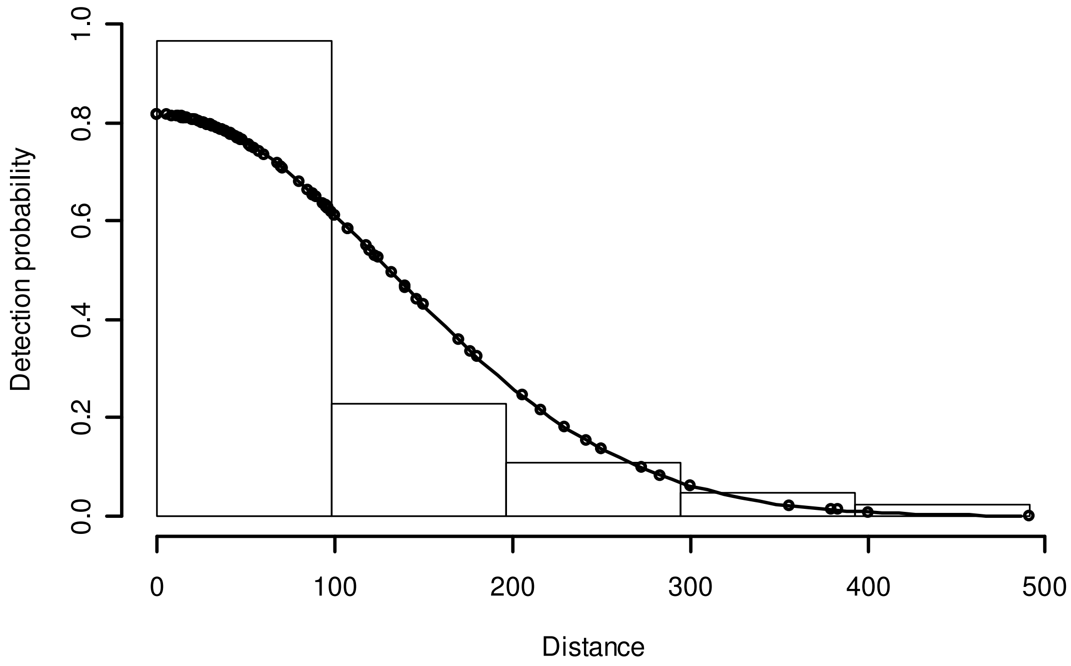

Figure 3.8: Fitted detection function of grey seal sightings (truncated at 500m) recorded by the primary observers during the 2003/04 surveys of Cardigan Bay SAC. The solid line shows detection function of the Mark-Recapture (MR) model that incorporates perpendicular distance as a covariate. The dots indicate the individual detection probability of each sighting.

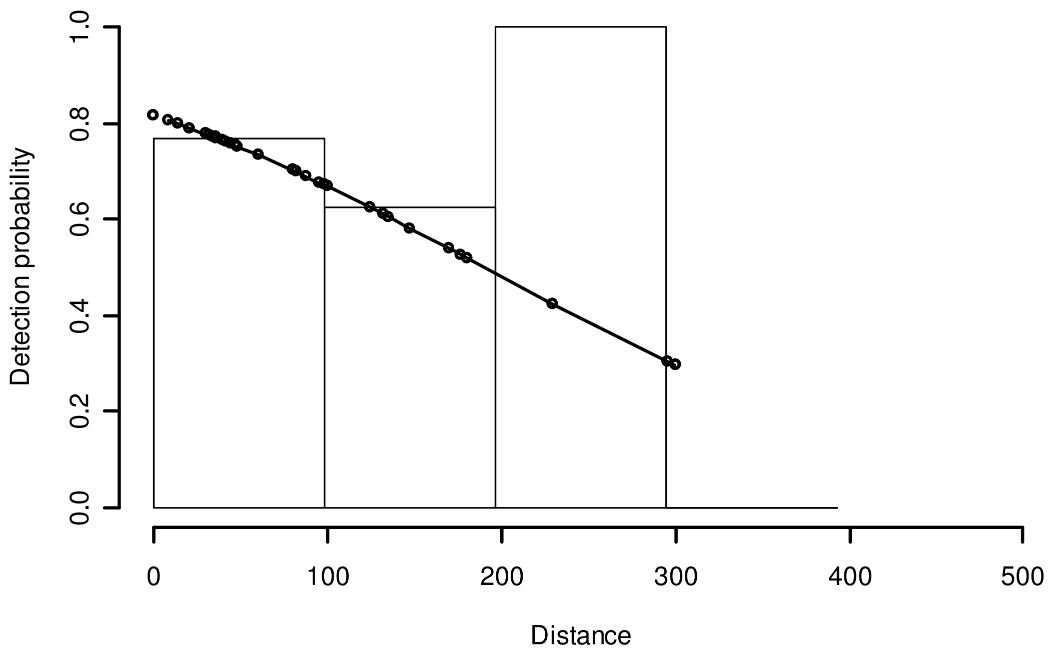

Figure 3.9: Histogram showing the probability of detection of duplicate sightings of grey seal with perpendicular distance (m) recorded during the 2003/04 surveys of Cardigan Bay SAC. The solid line shows the duplicate detection function of the Mark-Recapture (MR) model that incorporates perpendicular distance as a covariate. The dots indicate the individual detection probability of each sighting.

The MR model with the lowest AIC produced an estimate of $g(0)$ for grey seal of 0.815, which was slightly above that of the mean. This suggests that the primary observer detected approximately 82% of all grey seal on the trackline in 2003/04, indicating that grey seal are slightly more likely to be detected than bottlenose dolphin in the 2003/04 surveys.

Figure 3.8 shows the perpendicular sightings distribution of the sightings of grey seal recorded by the primary observer. The solid line shows the fitted MR model with perpendicular distance as the sole covariate. The histogram displayed a clear spike of sightings on or near to the trackline, beyond which the probability of each sighting dramatically decreased. The model overestimated the probability of detection between distances of 100-275m, but tended to fit the data relatively well near the trackline at the maximum truncation distance.

Figure 3.9 showed that the perpendicular sightings distribution of duplicate sightings with the MR model fitted with perpendicular distance as the sole covariate. Unlike the bottlenose dolphin duplicate detection function, the probability of detecting duplicate grey seal sightings decreased as the distance from the trackline increased. The conditional detection function parameter for perpendicular distance was -0.0078 (SE 0.0041) which supported this finding.

3.4.2.2 Grey Seal – The 2005 surveys

The qq-plots (see APPENDIX B) for the grey seal data recorded in the 2005 surveys indicated that the MR model was in fact a very good fit to the data. This was echoed in the perpendicular sightings distribution for the primary observers in figure 3.10. The chi square test statistic ($\chi = 4.170$, $p = 0.654$, 6 df) and the Kolgomorov-Smirnov test statistic (0.079. $p = 0.880$) both confirmed this. As expected the chi-square statistic for the MR component of the model ($\chi = 3.273$, 2df, $p = 0.194$) indicated that any estimates of $g(0)$ were valid.

Model definition	No. of Parameters	ΔAIC	AIC	*g*(0)
MR dist+exp	5	0.00	660.56	0.934
MR dist+exp+sea	6	0.67	661.23	0.934
MR dist+exp+swell	6	0.95	661.51	0.932
MR dist	3	1.79	662.35	0.945
MR dist+exp+sea+swell	7	2.56	663.12	0.933
MR dist+sea	4	2.94	663.50	0.944
MR dist+swell	4	3.49	664.05	0.946
MR dist+exp+sea_swell	8	4.42	664.98	0.935
MR dist+sea(FACT)	6	4.81	665.37	0.948
MR dist+sea+swell	5	4.91	665.47	0.944
Peterson	2	6.44	667.00	0.744
MR dist+sea_swell	6	6.69	667.25	0.945

Table 3.11: The model definition formula, number of parameters, Akaike Information Criterion (AIC) value, and estimated *g*(0) for the fitted detection function for grey seal data collected in line transect surveys of Cardigan Bay SAC in 2005.

Group size was not included as a covariate in the analysis of the grey seal data from the 2005 surveys. This was due to the fact that every sighting was of an individual seal and thus group size would have no differential effect on the probability of detection of each sighting. Estimates of *g*(0) for grey seal in the 2005 surveys ranged from 0.744-0.948 ($\bar{x}$ = 0.924, SE = 0.0164) compared to 0.667-0.831 ($\bar{x}$ = 0.806, SE = 0.012) in the 2003-2004 surveys. The MR model which included perpendicular distance and observer experience as covariates (AIC = 660.56) was selected by AIC as the best fitting model to the grey seal data from the 2005 surveys. This model produced an estimate of *g*(0) for grey seal in 2005 of 0.934, which suggested that grey seal were detected by the primary observers with a similar certainty as bottlenose dolphin (*g*(0) = 0.941) in the same year.

Figure 3.10 indicates that there was only a slight decrease in the probability of the primary observers detecting grey seal out to 162m from the trackline. Beyond 162m the probability of detection decreases relatively rapidly with each distance interval. A similar pattern is observed in the duplicate detection function in figure 3.11 however, there was a more rapid decrease in the probability of detection of duplicate sightings after 162m than that observed of sightings detected by the primary observers.

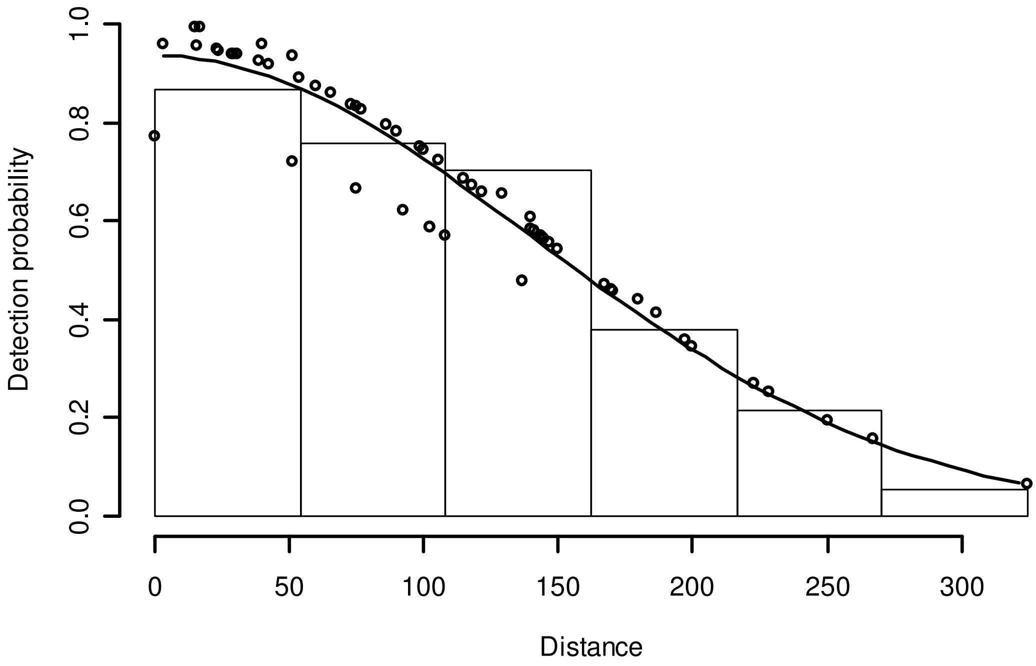

Figure 3.10: Fitted detection function of grey seal sightings (truncated at 350m) recorded by the primary observers during the 2005 surveys of Cardigan Bay SAC. The solid line shows detection function of the Mark-Recapture (MR) model that incorporates perpendicular distance and observer experience as covariates. The dots indicate the individual detection probability of each sighting.

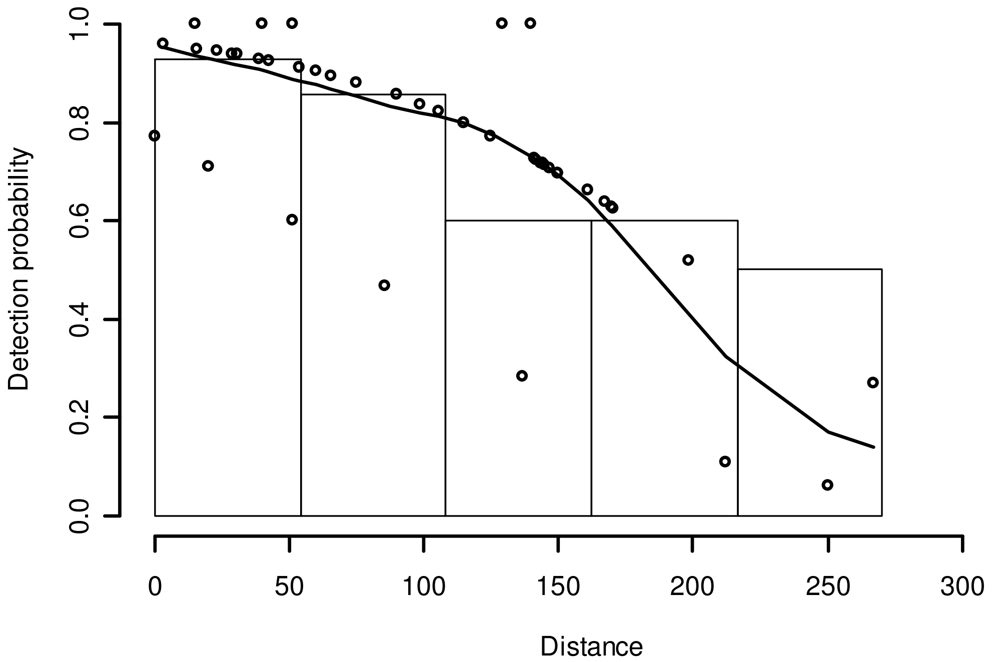

Figure 3.11: Histogram showing the probability of detection of duplicate sightings with perpendicular distance (m) of grey seal recorded during the 2005 surveys of Cardigan Bay SAC. The solid line shows the duplicate detection function of the Mark-Recapture (MR) model that incorporates perpendicular distance and observer experience as covariates. The dots indicate the individual detection probability of each sighting.

The positive sign of the conditional detection coefficient for observer experience (1.2067, SE 0.1081) in table 3.12 indicated that the probability of detecting grey seal at all distances was higher for more experienced observers than it was for lesser experienced observers. As expected, the conditional detection coefficient for perpendicular distance (-0.0156, SE 0.0073) indicated that the probability of detecting grey seal decreased with increasing perpendicular distance from the trackline.

	Coefiicients	SE
Intercept	1.2067	0.1081
Perpendicular distance	-0.0156	0.0073
Observer experience	1.9712	0.1086

Table 3.12: The conditional detection function parameters, and their SE, for the explanatory variables in best fitting model of the detection function (selected by AIC), for grey seal sightings in the 2005 surveys of Cardigan Bay SAC.

3.4.3 HARBOUR PORPOISE

3.4.3.1 Harbour porpoise – The 2003/04 surveys.

Both the qq-plot for the fitted cdf against the edf (see APPENDIX B) and the primary observer detection function (Figure 3.12) show that the MR model was a better fit to the harbour porpoise than both the bottlenose dolphin, and grey seal data from the 2003/04 surveys. The total chi-square test indicates that the data fits the model ($\chi = 6.62$, 7 df, $p= 0.469$) however, the Kolmogorov-Smirnov test statistic indicates that the cdf departs significantly from the edf (0.150, $p = 0.008$) and thus the overall model is a poor fit to the data. The difference in the results from the test statistic was due to differences in the statistical power of each test, and as the Kolmogorov-Smirnov test had a higher statistical power it was concluded that the model was a poor fit to the data. The MR component of the model fitted the data ($\chi = 1.187$, 3df, $p = 0.756$) indicating that any estimates of $g(0)$ were valid.

Model definition	**No. of Parameters**	**ΔAIC**	**AIC**	***g*(0)**
Peterson	2	0.00	1534.84	0.678
MR distance+size	4	1.12	1535.96	0.728
MR distance	3	1.52	1536.36	0.719
MR distance+size_sea	6	2.48	1537.32	0.735
MR distance+size+year	5	2.51	1537.35	0.722
MR distance+size_year	6	2.76	1537.60	0.733
MR distance+year	4	2.86	1537.70	0.712
MR distance+size+sea	5	2.98	1537.82	0.729
MR distance+sea	4	3.38	1538.22	0.720
MR distance+size+sea+year	6	4.42	1539.26	0.723
MR distance+sea+year	5	4.78	1539.62	0.713
MR distance+sea_year	6	6.07	1540.91	0.733

Table 3.13: The model definition formula, number of parameters, Akaike Information Criterion (AIC) value, and estimated *g*(0) for the fitted detection function for harbour porpoise data collected in line transect surveys of Cardigan Bay SAC in 2003/04.

Estimates of *g*(0) in table 3.13 range from 0.678-0.735 ($\bar{x}$ = 0.720, SE = 0.004) indicating that the primary observers detected harbour a higher percentage of harbour porpoise on the trackline than bottlenose dolphin. Despite the MR models relatively improved fit to the data, table 3.13 shows that the Peterson estimator was selected by AIC as the best fit the data (AIC = 1534.84). In spite of this, the Petersen estimator is more of a mathematical calculation rather than a statistical model and does not allow for the inclusion of covariates thus, in this case the next highest model according to AIC will be used. The next best fitting model was the MR model that incorporated perpendicular distance and group size as covariates (AIC = 1535.36). This model produced an estimate of *g*(0) of 0.728 indicating that 73% of all harbour porpoise on the trackline in 2003/04 surveys were detected by the primary observers.

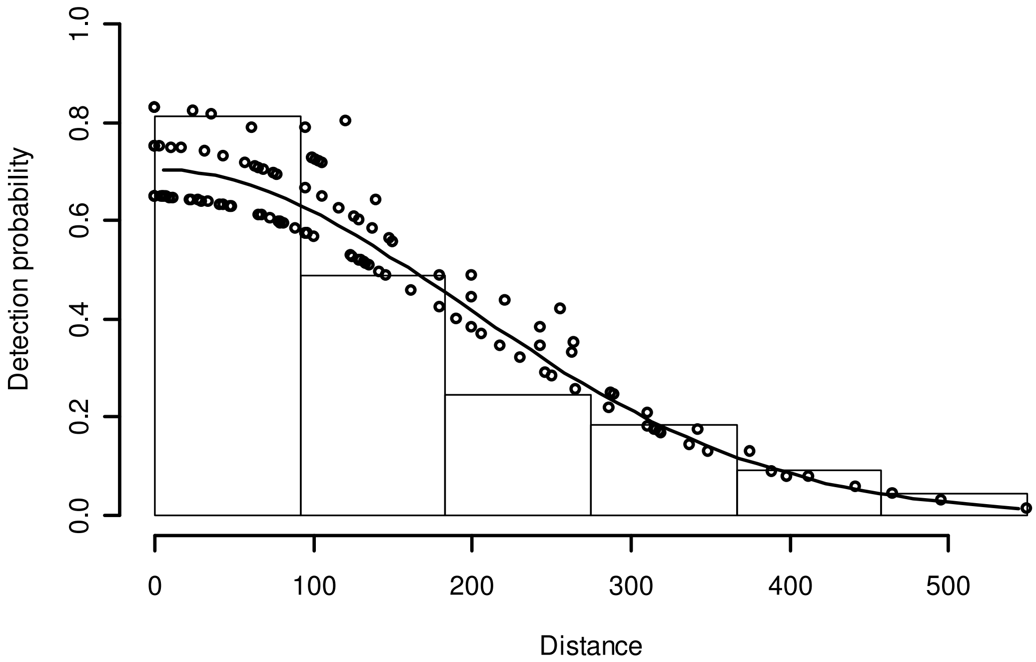

Figure 3.12: Perpendicular distance (m) distribution of harbour porpoise sightings (truncated at 550m) recorded by the primary observers during the 2003/04 surveys of Cardigan Bay SAC. The solid line shows detection function of the Mark-Recapture (MR) model that incorporates perpendicular distance and group size as covariates. The dots indicate the individual detection probability of each sighting.

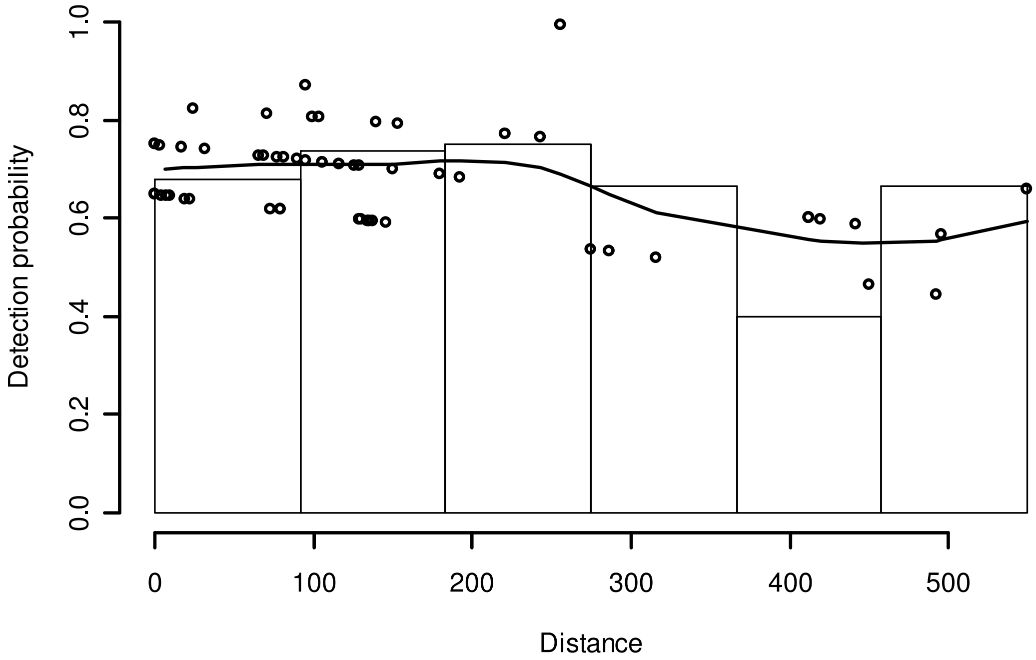

Figure 3.13: Histogram showing the probability of detection of duplicate sightings of grey seal with perpendicular distance (m) recorded during the 2003/04 surveys of Cardigan Bay SAC. The solid line shows the duplicate detection function of the Mark-Recapture (MR) model that incorporates perpendicular distance and group size as covariates. The dots indicate the individual detection probability of each sighting.

Figure 3.12 confirms that the MR model fitted the data better than both the bottlenose dolphin and grey seal data from the 2003/04 surveys. There was far less spiking near distance 0 although the model seemed to underestimate the detection probability near the trackline, which could potentially bias any estimates of $g(0)$ further. Figure 3.13 indicates that the model predicts little of no change in the detection probability of duplicate sightings within 250m of the trackline, beyond which the probability of detecting a duplicate sighting decreases.

	Coefficients	SE
Intercept	0.1182	0.7391
Perpendicular distance	-0.0017	0.0019
Group size	0.4889	0.3854

Table 3.14: The conditional detection function parameters, and their SE, for the explanatory variables in best fitting model of the detection function (selected by AIC), for harbour porpoise sightings in the 2003/04 surveys of Cardigan Bay SAC.

Table 3.14 shows that group size has a large positive value indicating that larger groups are more detectable than smaller groups at all distances. This evidence supported the shape of the fitted model in figure 3.13 and suggested that larger groups were sighted within 250m of the trackline. Beyond 250m smaller groups were sighted and thus the detection probability decreased due to the small negative value of the conditional detection function parameter for perpendicular distance.

3.4.3.2 Harbour porpoise – The 2005 surveys

The qq-plot (see APPENDIX B) and the fitted detection function (Figure 3.14) both indicated that the MR model provided a good fit to the harbour porpoise data from 2005 surveys. The total chi-square statistic ($\chi = 10.588$, $p = 0.158$, 7 df) and Kolgomorov-Smirnov test statistic (0.080, $p = 0.555$) both confirm this. Furthermore, the chi-square statistic for the MR component of the model ($\chi = 4.540$, 3df, $p = 0.209$) indicated that any estimates of $g(0)$ were valid.

Model definition	**No. of Parameters**	**ΔAIC**	**AIC**	***g*(0)**
MR dist+size	4	0.00	1266.94	0.811
MR dist+size+sea	5	1.87	1268.81	0.813
MR dist+size+cue	5	1.92	1268.86	0.812
MR dist+size+exp	6	3.01	1269.95	0.822
MR dist+size+swell	6	3.56	1270.50	0.812
MR dist+size+sea+cue	6	3.83	1270.77	0.814
Peterson	2	4.86	1271.80	0.667
MR dist+size+sea+exp	7	4.89	1271.83	0.824
MR dist	3	4.98	1271.92	0.777
MR dist+size+cue+exp	7	4.99	1271.93	0.822
MR dist+size+sea+swell	7	5.55	1272.49	0.813
MR dist+size+sea:swell	7	5.80	1272.74	0.813
MR dist+sea	4	6.30	1273.24	0.784
MR dist+size+sea+exp+cue	8	6.89	1273.83	0.824
MR dist+cue	4	6.98	1273.92	0.778
MR dist+sea+cue	5	8.29	1275.23	0.784
MR dist+swell	5	8.33	1275.27	0.782
MR dist+exp	5	8.47	1275.41	0.787
MR dist+sea (FACT)	6	9.38	1276.32	0.774
MR dist+sea+swell	6	9.81	1276.75	0.789
MR dist+sea+exp	6	9.85	1276.79	0.793
MR dist+sea_swell	6	9.98	1276.92	0.791
MR dist+size+sea+exp+cue+swell	10	10.70	1277.64	0.823
MR dist+sea+cue+exp	7	11.78	1278.72	0.793
MR dist+sea+exp+cue+swell	9	15.37	1282.31	0.799

Table 3.15: The model definition formula, number of parameters, Akaike Information Criterion (AIC) value, and estimated $g(0)$ for the fitted detection function for harbour porpoise data collected in line transect surveys of Cardigan Bay SAC in 2005.

Table 3.15 displays the variety of combinations of covariates included in the MR model and the subsequent AIC and estimates of $g(0)$ that were produced. Estimates of $g(0)$ for harbour porpoise in the 2005 surveys ranged from 0.667-0.824 ($\bar{x}$ = 0.796, SE = 0.006) compared to 0.678-0.735 ($\bar{x}$ = 0.720, SE = 0.004) in the 2003-2004 surveys. The MR model chosen by AIC as the best fitting model to the harbour porpoise data from the 2005 surveys was the model that included perpendicular distance and group size as covariates (AIC = 1266.94). This model produced an estimate of $g(0)$ of 0.811, indicating that approximately 81% of harbour porpoise on the trackline were detected by the primary observers in the 2005 surveys compared to 73% in the 2003-2004 surveys.

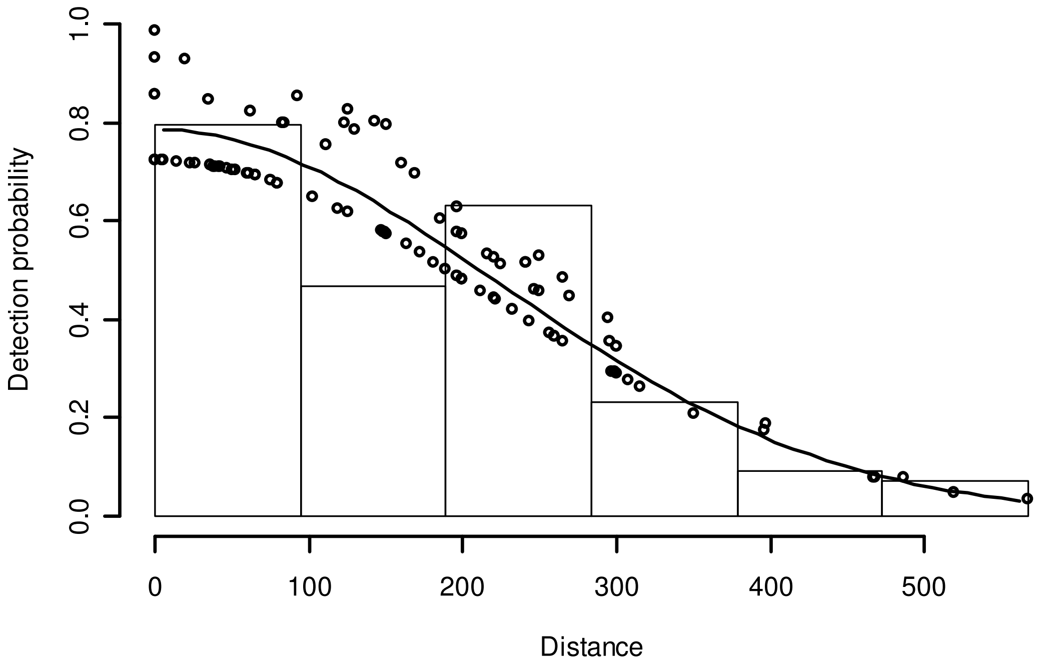

Figure 3.14: Fitted detection function of harbour porpoise sightings (truncated at 570m) recorded by the primary observers during the 2005 surveys of Cardigan Bay SAC. The solid line shows detection function of the Mark-Recapture (MR) model that incorporates perpendicular distance and group size as covariates. The dots indicate the individual detection probability of each sighting.

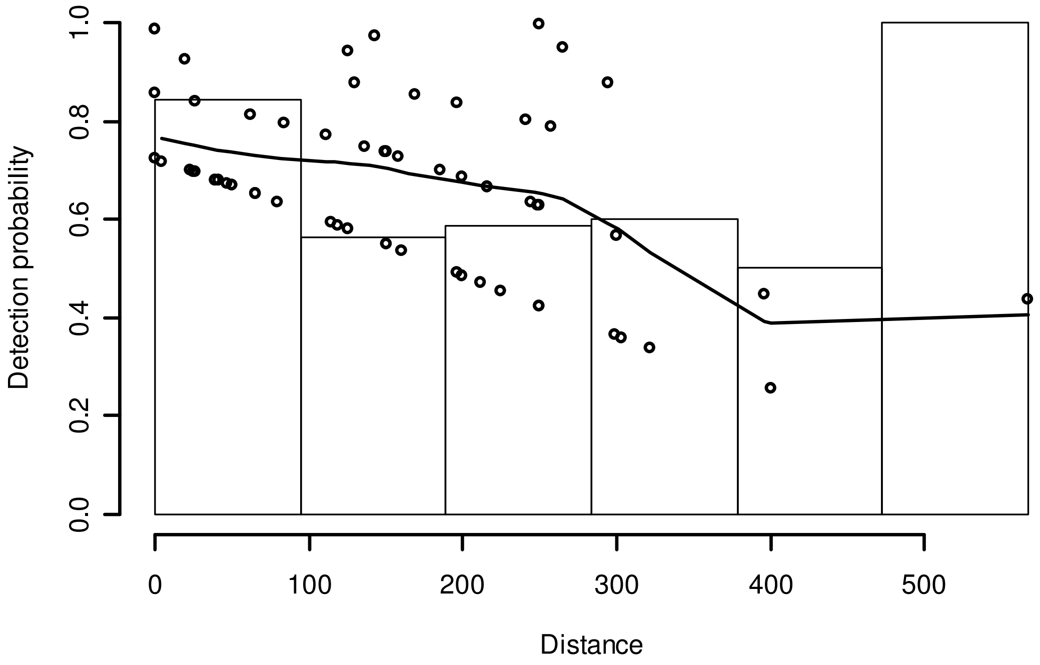

Figure 3.15: Histogram showing the probability of detection of duplicate sightings with perpendicular distance (m) of harbour porpoise recorded during the 2005 surveys of Cardigan Bay SAC. The solid line shows detection function of the Mark-Recapture (MR) model that incorporates perpendicular distance and group size as covariates. The dots indicate the individual detection probability of each sighting.

Figure 3.15 shows that the probabilities of detection for duplicate sightings decreased steadily with increasing perpendicular distance. The negative value of the conditional detection function parameter for perpendicular distance (-0.0050, SE 0.0027) in table 3.16 explains why this pattern was observed.

	Coefficients	SE
Intercept	0.1268	0.6976
Perpendicular distance	0.0050	0.0027
Group size	0.8285	0.3969

Table 3.16: The conditional detection function parameters, and their SE, for the explanatory variables in best fitting model of the detection function (selected by AIC), for harbour porpoise 2005 surveys of Cardigan Bay SAC.

The conditional detection function coefficient for group size (0.8285, SE = 0.3969) in table 3.16 had a positive sign indicating that larger groups were more detectable at any given distance from the trackline. The probability of detection of duplicate sightings, as indicated by fitted model (solid line) in figure 3.15, decreased slowly out to approximately 280m, beyond which the probability of detection decreased at a greater rate out to 400m. This suggests that a higher number of larger groups were detected within the 300m of the trackline. Beyond 400m the probability of detection of duplicate sightings steadily increased out to the truncation distance. This is due to a single sighting at approximately 560m from the trackline and thus this change in detection probability of duplicate sightings was an artefact of a low sample size in that distance interval and can be ignored.

4. DISCUSSION

4.1 ESTIMATES OF G(0)

4.1.1 Bottlenose Dolphin

Estimates of *g*(0) for bottlenose dolphin detected during line transect surveys of Cardigan Bay SAC, was 0.705 for the 2003/04 surveys, and 0.941 for the 2005 surveys. The estimate of *g*(0) obtained here for bottlenose dolphin in the 2005 surveys (0.941) is similar to that of the estimate obtained by Palka (2005b) of 0.93 (CV = 0.61) for bottlenose dolphin in the Northwest Atlantic. G(0) for bottlenose dolphin in the combined 2003/04 studies was far less than both the 2005 estimate in this study, and the estimate of *g*(0) produced by Palka (2005b). As previously mentioned, the 2003 and 2004 surveys of Cardigan Bay SAC each suffered from a very low number of bottlenose dolphin sightings and thus the data sets were combined to improve the sample size. When sample size becomes small the accuracy and precision of line transect estimators becomes markedly reduced (Barlow *et al.* 2001). In the 2003/2004 surveys there were only 15 duplicate sightings of bottlenose dolphin of which, only 7 were detected by the IO within 100m of the trackline. This low sample size will ultimately lead to unreliable estimates of *g*(0), density and abundance.

The primary observers in the 2005 surveys detected approximately 94% of all bottlenose dolphin on the trackline. This estimate of *g*(0) suggests that any estimates of density and abundance of bottlenose dolphin obtained from surveys were *g*(0) cannot be estimated, would be encounter negligible negative bias under the assumption that *g*(0) = 1. However, the 2003/04 surveys indicate that the primary observers only detected approximately 71% of bottlenose dolphin on the trackline. Despite the potential unreliability of the 2003/04 estimates of *g*(0) due to low sample size, it would be unwise to assume that *g*(0) ≈ 1 for bottlenose dolphin based on the 2005 result alone. All future surveys of Cardigan Bay SAC should consider the use of independent observers, in order to establish 1), if *g*(0) is consistently ≈ 1 for all surveys with sufficiently large sample size, and 2), if there are large variations in estimates of *g*(0) for bottlenose dolphin between years, in surveys where sample size is sufficiently large.

4.1.2 Grey Seal

The estimates of *g*(0) for grey seal in Cardigan Bay SAC were 0.815 in the 2003/04 surveys to 0.934 in 2005 surveys. This indicated that the primary observers missed approximately 18% of the grey seal on the trackline in 2003/04 compared to only 7% in 2005. There are no other estimates of *g*(0) for seal from shipboard surveys to allow for a comparison of these results however, several inferences can be made form this data alone. Both datasets contained a reasonable number of trackline IO sightings (28 in 2003/04, 20 in 2005) from which reliable estimates of *g*(0) could be obtained and thus neither dataset was hampered by a particularly low sample size. It would be reasonable to assume that any estimates of density and abundance for grey seal in Cardigan Bay SAC, obtained using the 2005 dataset with the assumption of $g(0) \approx 1$, would experience a negligible level of negative bias. However, this approach would not be recommended using the 2003/04 data as estimates will be underestimated by a factor approaching 20%.

It is reasonable to assume that estimates of *g*(0) for grey seal to be relatively high even though the proportion of there body available for detection at sea is relatively small. Seals, unlike cetaceans, often spend large periods of time available for detection on the sea surface. While resting between dives, seals are often seen ‘logging’ at the sea surface. A study by Beck *et al.* (2003) suggests that male and female grey seals spend an average of 2.2 and 2.4 minutes at the surface between dives respectively. Behavioural data recorded during the surveys often revealed that seals that surface within 100m of the trackline and would often stay at the surface and watch the boat as it passed by. Only if the seals were within approximately 50m of the vessel, would they dive shortly after surfacing. This behaviour increases the availability of grey seal for detection by the primary observers, even when environmental conditions are unfavourable for detection on the trackline. With this in mind, the difference in the estimates of *g*(0) in this study may well be due to observer awareness, or possible even the difference in survey vessel used, rather than environmental conditions. (The importance of covariates in the analysis is discussed in later). Further study will reveal if *g*(0) is consistently high (≈ 0.9) using the 2005 survey vessel (*Dunbar Castle II*).

4.1.3 Harbour Porpoise

The estimates of *g*(0) for harbour porpoise in this study were consistently lower than the estimated *g*(0) for bottlenose dolphin. *G*(0) for harbour porpoise was estimated to be 0.728 for 2003/04 surveys, and 0.811 for the 2005 surveys of Cardigan Bay SAC. There have been numerous estimates of *g*(0) for harbour porpoise from ship based line transect surveys. *G*(0) for harbour porpoise has been estimated as 0.31 (CV = 0.15) in the North Sea (Hammond *et al.* 2002), 0.780 in the waters off California (Barlow 1988), ranging from 0.619-0.736 in various locations in the Northwest Atlantic (Palka 2000), and 0.53 (CV = 0.51) in the waters off Washington State (Calambokidis 1998). Furthermore, estimates of *g*(0) for similar species, such as the vaquita (*Phocoena sinus*), are also low at 0.571 (CV = 0.33) (Jaramillo-Legorreta *et al.* 1999). Barlow *et al.* (1997) summarized that estimated *g*(0) for harbour porpoise in shipboard surveys tends to range from 0.4 – 0.78. Encouragingly, the estimates of *g*(0) produced in this study are at the top end of the range stated by Barlow *et al.* (1997) indicating that the trackline sightings efficiency of the primary observer in this study were higher than most other surveys.

Estimates of *g*(0) for harbour porpoise in the 2003/04 surveys were not hampered by low sample size. The 2003 and 2004 surveys, both contained a relatively low number of trackline IO sightings (9 and 18 respectively), but when combined sample size was greatly improved. Pooling both the 2003 and 2004 data was a feasible option as studies have shown perpendicular sightings distances recorded from the same vessel, between years show no significant differences (Barlow *et al.* 2001). This is echoed in the results from this study as year was not selected by AIC as a significant covariate in influencing the shape of the detection function.

This study suggests that approximately 73-81% of harbour porpoise on the transect line were missed by the primary observers. This suggests that any density and abundance estimates derived from the datasets used in this study would potentially be underestimated by factors of 27% (2003/04 surveys) and 19% (2005 surveys). Caution must be taken when comparing estimates between years when differing surveys vessels, environmental conditions, and surveys procedures were used (Cañadas *et al.* 2004), however, the consistency of estimates of $g(0)$ for harbour porpoise within Cardigan Bay SAC, and other study areas suggest that if its is assumed that $g(0) = 1$, then all density and abundance estimates will be grossly underestimated. Furthermore the potential for $g(0)$ estimates to vary by a factor ≈ 10% between years, suggests that any true trends in abundance may be masked by variations the true value of $g(0)$ with each year.

4.2 THE IMPORTANCE OF COVARIATES

Analysis using DISTANCE allowed for the incorporation of covariates into the detection function in order to investigate which environmental and behavioural variables had a significant effect on the probability of detection at all distances. It has been well documented that group size, Beaufort sea state, swell, observer experience, and detection cue introduce the large amount of detection bias at large perpendicular distances $x>0$ (Buckland and Turnock 1992; Borchers *et al.* 1998a, 1998b; Palka and Hammond 2001; Borchers 2005), but heterogeneity in detection occurs at all distances, including at distance $x = 0$ (Cañadas *et al.* 2004).

4.2.1 Group Size

Group size was consistently selected by AIC as the most important covariate that was likely to introduce heterogeneity in detection in bottlenose dolphin and harbour porpoise sightings, in both the 2003/04 and 2005 surveys. When cetaceans surface while swimming, they are only visible for 1-2 seconds, before diving. This characteristic makes small cetaceans notoriously difficult to detect, even on the trackline. However, species such as bottlenose dolphin (and to a lesser extent, harbour porpoise) are often found in groups which become more detectable to the primary observers for two reasons. Firstly, larger groups form bigger, more obvious targets for detection at any one time and secondly, cetaceans in groups often surface at different times which collectively increases the total time that the observers are able to detect an animal within the group. Mean group sizes for bottlenose dolphin were (3.82 (SD = 2.93) and 2.76 (SD = 1.99) in the 2003/04 and 2005 surveys respectively) consistently >1 animal per group, and the relatively large standard deviations indicate that there was substantial variation in group size around the mean. Mean group sizes for harbour porpoise were smaller than that of bottlenose dolphin (1.74 (SD= 1.19) and 1.75 (SD = 1.35) in 2003/04 and 2005 surveys respectively) with less (but still considerable) variation around the mean estimate. This variation in group size, coupled with relatively high mean group sizes for bottlenose dolphin and harbour porpoise, was likely to introduce large amounts of heterogeneity bias into the detection function. Studies by Barlow (1988) and Hammond *et al.* (2002) identified group size as a major source of heterogeneity in harbour porpoise estimates, and these findings support the results of this study. However, a study by Palka (2005b) did not identify group size as a significant covariate affecting the estimation of $g(0)$ for offshore bottlenose dolphin. T-test also revealed that group size of bottlenose dolphin differed significantly with each tear. This suggests that comparisons of estimates of $g(0)$ that do not consider group size as a covariate, would be inherently biased.

4.2.2 Beaufort Sea State

Beaufort sea state was only selected by AIC as being a potentially significant covariate influencing the detection for bottlenose dolphin in the 2005 surveys. It has been well documented that increasing sea states can introduce a large negative bias into line transect estimates (Cañadas *et al.* 2004). Palka (1996) justified this by stating that as sea state increases, heterogeneity in detection increases and larger/more conspicuous objects tend to be frequently detected by both teams (as duplicates) whereas smaller, more inconspicuous objects are missed by both teams. As a result $g(0)$ is biased upwards which consequently has a negative bias on overall density and abundance estimates. However, Barlow *et al.* (2001) suggested that perpendicular sighting distance is only negatively, linearly related to Beaufort sea state in sea states of 2 or more. That is to say that if surveys are predominantly conducted in low sea states, then heterogeneity bias is somewhat reduced. For example, Beavers and Ramsey (1998) identified sea state as the overriding factor influencing the detection of sea turtles in line transect surveys with a mean sea state of 1.54 (SD = 1.54). The large standard deviation around this mean estimate suggests that survey conditions varied significant around the moderately low mean sea state of 1.54. Mean sea states in the 2003/04 surveys ($\bar{x}$ = 1.07, SD = 0.72) in this study were lower than those surveyed by Beavers and Ramsey (1998), as well as having less than half the variation around the mean. This may explain to some extent why sea state was not found to be a significant covariate in any of the analyses from the 2003/04 surveys, as the vast majority of effort was performed in very low sea states, which have been identified as introducing only negligible bias into line transect estimates. In contrast, the mean sea state of the 2005 surveys ($\bar{x}$ = 1.50, SD = 0.88) was significantly higher than that of the 2003/04 surveys suggesting that a higher proportion of the effort was performed in sea states ≥2, and thus all recorded sightings may have been susceptible to increased heterogeneity bias. It is unusual that sea state was not deemed a significant covariate in the detection of harbour porpoise which are smaller, and more inconspicuous than bottlenose dolphin (Barlow 1988). Sea state has been frequently associated with a reduction in the probability of detection of harbour porpoise (Barlow 1988; Palka 1996; Carretta *et al.* 2001; Hammond *et al.* 2002). This result suggests that there may have been increased observer awareness for smaller animals such as harbour porpoise in this study, or possibly that there were so few sightings of harbour porpoise during periods of effort when sea state was ≥2 that less bias was incorporated into the data. Either way, more work needs to be carried out to investigate the true extent of the effect of sea state on the detection of marine mammals in Cardigan Bay SAC.

Sea state seemed to have little of no influence over the detection of grey seal in both the 2003/04 surveys. This is most probably explained by the large amount of time seals spent at the surface between dives which resulted in increased availability for detection by the primary observers.

4.2.3 Swell

Sea state alone does not give an accurate description of the se surface characteristics (Barlow *et al.* 2001) as it does not account for the pitch and fall of the ocean created by swell. Swell was only incorporated into the MR model for the 2005 surveys and was not selected by AIC as a significant covariate affecting the detection of all 3 species. Barlow (1988) identified large swell (>3m) as a major reason why observers failed to detect harbour porpoise in shipboard surveys off the Californian coast. However, Cardigan Bay SAC is located on a semi sheltered region of coastline within the Irish Sea and rarely experiences swells >3m during the summertime, when the study was carried out. The lack of any significant swell during the study period in 2005 and the relative consistency of small swells during this time, may well explain why swell was not identified as an important factor influencing detection. This is not to say that the recording of swell in future surveys should be discarded, as there could be significant differences in swell with each study period.

4.2.4 Observer experience

Observer experience proved to be a significant covariate affecting the probability of detection of bottlenose dolphin and grey seal in the 2005 surveys. The conditional detection function parameters for observer experience in the 2005 bottlenose dolphin and grey seal detection functions had a positive sign suggesting that the more experienced the observer, the more likely it is that they will detect the animal. Grey seals resting at the surface can easily be mistaken as seabirds, and it often requires an experienced observer to correctly identify these sightings as grey seal. This may have influenced the result here as lesser experienced observers would detect the same animal if it were closer to the ship. Bottlenose dolphins are large animals and easily detected on the trackline thus it is therefore likely that the full effect of observer experience on the probability of detecting dolphins occurs at distances $x>0$. However, this assumption requires clarification and future studies could estimate $g(0)$ for bottlenose dolphin for experienced and inexperienced observers separately to reveal its full effect on trackline sightings.

Observer experience did not affect the probability of detection of harbour porpoise. Harbour porpoise are notoriously difficult to detect, however these results suggest that all observers detected harbour porpoise at any given distance with equal probability. This is unlikely as Laake *et al.* (1997) suggested that in ideal sightings conditions (sea state 0, good visibility) experienced observers on aerial surveys can detect and identify all harbour porpoise on the trackline with an efficiency approaching 90-100% ($g(0) \approx 1$) compared to only 25% for inexperienced observers. It is clear that further work is needed to determine the extent of how observer experience affects the probability of detecting harbour porpoise in shipboard surveys in Cardigan Bay SAC

Observer experience is notoriously hard to quantify (Barlow *et al.* 2001) and method used to incorporate observer experience in this study may not account for the full bias introduced by through observer experience. One approach to cope with this problem would be to train all new/inexperienced observers on practise cruises to test there sightings efficiency compared to experienced observers, before including them in research cruises. This approach would be costly and potentially impractical for smaller, less affluent organisations that may not have the facilities or funding for this. Further work is required to ascertain the most practical way of incorporating the effect of observer experience into the detection function and estimates of $g(0)$.

4.2.5 Cue

The cue given off by the animal which alerts the observers as to the position of the animal had no effect on estimates of $g(0)$ for each of the species in the 2005 surveys. The vast majority of the cues produced by the two cetacean species in this study involved the brief presentation of the dorsal fin and dorsal surface of the body, whilst surfacing during normal swimming behaviour. This was especially true for harbour porpoise, where 97% of all the cues detected by both sets of observers were of the dorsal fin. As previously discussed grey seal often rest at the surface between dives with only their head above the water available for detection. Grey seal rarely produced any splash at the surface and thus the cues detected by the primary observers were consistent across the whole of the study period. The high number of small, consistent cues produced by grey seal and harbour porpoise are unlikely to introduce any significant amount of heterogeneity bias into the detection function.

Bottlenose dolphins often display highly conspicuous surface behaviour, such as leaping and tail slapping, when feeding and interacting in social situations (Wells and Scott 2002). When these types of behaviours are performed within the visual range of observers on a shipboard survey, they produce highly visible cues (and audible cues if sufficiently close to the observers) that are easily detected by the observers in most survey conditions. In this situation there is great potential for heterogeneity bias to be introduced into the detection function as a result of different cues. However, in this study only 12% of all cues from bottlenose dolphins that were detected by the primary observers involved this highly visible behaviour, which may not have been enough to introduce significant bias into the detection function. Its is clear that if a species of marine mammal has the potential to perform a variety of behaviours at the sea surface, then the more visible cues are likely to be preferentially detected by the primary observers, which can potentially bias any estimates of $g(0)$ if not accounted for.

4.3 POTENTIAL LIMITATIONS

It is well documented that the more one is able to incorporate covariates that introduce heterogeneity into the model, then the accuracy of any estimates of $g(0)$ will become (Borchers 2005). However, the incorporation of covariates into the model will depend on the observers' ability to record these factors accurately (Laake 1999), and this may vary between studies, as well as between observers within studies. The methods used in this study reduced the effect of heterogeneity bias, both in survey design and analysis, yet there are areas where bias may have affected any estimates of $g(0)$.

4.3.1 Responsive Movement

One such area is due to the responsive movement of the animals in response to the approaching vessel. Line transect theory is based around the assumption that animals do not move in response to the vessel before they are detected by the observers. Marine mammals such as common dolphin are frequently seen bow-riding and it has been shown that they are predominantly attracted towards oncoming vessels (Cañadas *et al.* 2004). If this is a case during line transect surveys then the detection function will be negatively biased and consequently, abundance of the species will be overestimated (Borchers 2005). Conversely, if marine mammals avoid oncoming vessels then the detection function will be positively biased and abundance will be underestimated. Techniques that involve tracking platforms that search ahead of the primary observers using high powered binoculars have been developed to account for responsive movement in ship-based line transect surveys (Turnock and Quinn 1991; Buckland and Turnock 1992, Borchers *et al.* 1998a, 1998b). These methods require the tracker platform to track the animals' movement in response to the vessel prior to detection by the primary observers thus, allowing for the inclusion of a correction factor for responsive movement in the data analysis. These methods require the tracker platform to be placed on an area with suitable elevation above the sea surface to allow for the observation of any responsive movement. Unfortunately the vessels used in this study are small, and only have one semi-elevated area at which the primary observers were already placed. Furthermore, the use of binoculars on small flat keeled boats such as *Dunbar Castle II* is particularly difficult in rougher seas as the boat is extremely susceptible to pitch and roll. Both these factor meant that the methods devised by Buckland and Turnock (1992) could not be implemented effectively.

Studies on the behaviour of bottlenose dolphins in relation to boat traffic in Cardigan Bay SAC during the summers of 2002 and 2003 (Pierpoint and Allen 2004) suggest that bottlenose dolphin predominantly display 'staying' behaviour (remain in similar position) in approximately 50-60% of all the sightings when in the presence of visitor passenger boats similar to *Sulaire* and *Dunbar Castle II.* The spiking of sightings close to the trackline in the 2003/04 and 2005 bottlenose dolphin detection functions suggest that some responsive movement towards the vessel may have occurred. This may well have negatively biased any estimates of $g(0)$ (particularly in the 2003/04 surveys) although the extent of responsive movement of bottlenose dolphins in these surveys cannot be determined or properly accounted for.

Harbour porpoise are regarded as shy animals and rarely approach boats (Cresswell and Walker 2001). It has been suggested that harbour porpoise will avoid oncoming boats wherever possible (Palka 2000) although the extent and direction of their avoidance behaviour remains uncertain (Hammond *et al.* 2002). The perpendicular sightings distributions for sightings of harbour porpoise and grey seal by the primary observers from the 2005 study suggest that there may have been an avoidance reaction displayed by both species in relation to the vessel. A secondary peak of harbour porpoise sightings was observed within the 100-300m distance interval, and the primary peak of grey seal sightings was recorded in the 100-150m interval. This would serve to over estimate $g(0)$ and subsequently underestimate abundance estimates for these species. Unfortunately, there was no way of accounting for responsive movement using the current survey and analysis methods.

4.3.2 Measurement Errors

Another important assumption of line transect theory assumes that all distances and angles to sightings are measured accurately. This assumption is met with reasonable accuracy in terrestrial surveys however, in ship-based marine surveys there is greater potential to introduce error into distances estimates for numerous reasons. Firstly, sightings of marine mammals predominantly comprise of very brief and often discrete encounters when an animal emerges from the water to breath before diving once more. Observers often catch a glimpse of the animal before it dives and then have to estimate the distance to the area of sea where the animal emerged, rather than at the actual animal itself. Estimation of distance at sea is notoriously difficult (Buckland *et al.* 2001) as the sea surface lacks any permanent reference points form which to base estimates from. Reticulated binoculars can be used to estimate radial distance with reasonable accuracy, but this technique requires a stable platform from which to calibrate distance from the position of the horizon, which was not possible in this study due to the heavy pitch and roll of the ship. New techniques have been investigated such as using the horizon in photographs to accurately calculate the distance, although these methods are still in development, they require the observation platform to be >6m above sea level (Gordon 2001), which can not be achieved using the research vessels in this study.

This study required estimation of the radial distance to sighting by sight alone. Despite it being well documented that this method of distance estimation is prone to errors (Buckland *et al.* 2001), it still represents the only consistent and practical option for use on smaller vessels. The magnitude of the error incorporated into any line transect estimator through measurement errors can be reduced, but not eradicated, by the thorough training of observers using fixed targets at sea.

4.3.3 Availability Bias

The procedures used in this study do account for heterogeneity in detection caused by perception bias, but do not account for availability bias. Observers are likely to have missed submerged animals that did not surface within the visual range of the observers' survey area. This discrete availability of submerged animals is not considered when estimating $g(0)$ and thus estimates of $g(0)$ are likely to be overestimated (Laake *et al.* 1997). This problem is particular well documented in the estimation of $g(0)$ for long-diving baleen whales (Barlow 1997; Schweder *et al.* 1999). These methods focus on tracking and recording of the surfacing patterns of all detected animals after their initial detection. These patterns are then compared surfacing processes, and dive patterns of the target species that have been calculated out side of the survey in previous work. Dive times for the three species of marine mammal recorded in this study have been estimated at 25.8 seconds for bottlenose dolphin (Mate *et al.* 1995), 44-103 seconds for harbour porpoise (Westgate *et al.* 1995), and 4.9-5.5 minutes for grey seal (Beck *et al.* 2003). The survey vessels in this study travelled at approximately 7-8 knots whilst on transect which means they vessel travelled approximately 225m a minute. It is therefore possible that vessel could have travelled 97m for each bottlenose dolphin dive, for 166-388m each harbour porpoise dive, and approximately 1130m for each grey seal dive. Although this is a somewhat crude approach it does suggest that is great potential, particularly for grey seal and harbour porpoise, for observers to miss submerged animals. If this is the case, then estimates of $g(0)$ may well be overestimated in this study.

Finally, there may well be numerous other covariates, such as glare, time of day, and observer fatigue, that have the potential to introduce bias into any estimates of the detection function and *g*(0). All future studies should record as many variables as possible as until all potential sources of bias are accounted for, estimates of *g*(0) will be biased to some extent.

4.4 CONSERVATION AND MANAGEMENT IMPLICATIONS

The justification for estimating *g*(0) in surveys for marine mammals within marine protected areas such as Cardigan Bay SAC is solely based around improving the accuracy of relative abundance estimates, in an effort to gain improved knowledge on the success of current management strategies. In order to assess marine mammal population size and its trends precisely, estimation of abundance must be calculated without the assumption that *g*(0) =1 (Okamura *et al.* 2003). Previous studies on harbour porpoise in the north western Atlantic have revealed that estimation of *g*(0) has been relatively consistent over consecutive study periods (Palka 2000). The results of this study challenge this finding, and has shown that variations in survey effort, survey conditions and sightings sample size, can greatly influence the estimated real value of *g*(0) within each survey period. Marine mammals are long lived animals and consequently it is often several years until changes in population size and structure become apparent (Hooker and Gerber 2004). Without accounting for the real values of *g*(0) in this study, and in any subsequent studies, abundance estimates of all three species will mask the true status of each species. If this is the case, then management strategies for the marine mammal species found within Cardigan Bay SAC may be undermined from the outset.

Cardigan Bay was given its Special Area of Conservation status due to the resident population of bottlenose dolphin found within its waters. As a result conservation of this species and its habitat has become the focus of management efforts within the area. The potential threats to bottlenose dolphin Cardigan Bay SAC outlined in the introduction, suggest that without adequate safety measures, there is a sufficient number of threats to threaten the status of marine mammal populations.

The principle behind the EU Habitats Directive is to maintain and improve diversity within European ecosystems through the implementation of the Nature 2000 network of SAC's. Consequently, special attention should also be paid to the status of harbour porpoise and grey seal populations within Cardigan Bay SAC as it has been suggested that these estimates could serve as indicators of the current status of marine mammals in the whole of West Wales (deBoar and Simmonds 2003). Furthermore, comparison of trends in abundance of marine mammals in Cardigan Bay SAC within estimates from around the UK are needed to shed some light on the current status of individual species on a much larger scale (Hammond *et al.* 2002). Before this can be achieved the true value of $g(0)$ must be accounted for.

4.5 CONCLUSIONS

The methods used in this study present a realistic option for scientists who lack a specific statistical background, to estimate values of $g(0)$ for marine mammal surveys. This study has revealed that any abundance estimates of harbour porpoise would be greatly underestimated if it was assumed that $g(0) \approx 1$. Estimates of $g(0)$ for bottlenose dolphin and grey seal in the 2005 surveys suggest that detection on the transect line for these species was approaching unity but, it would be inadvisable to assume $g(0) =1$ in future surveys as estimates of $g(0)$ as well as environmental variables, have been shown to vary significantly between years.

Group size, Beaufort sea state, and observer experience all proved to be important covariates with the potential to introduce heterogeneity bias into estimates of g(0). These covariates must be recorded in all future surveys as well as swell height, detection cue and any other environmental and behavioural factors that have the potential to influence the probability of detection of marine mammals.

If future surveys were unable to calculate $g(0)$ for bottlenose dolphin, grey seal and harbour porpoise in Cardigan Bay SAC, the values of $g(0)$ estimated in this study could be used. This approach is not without its own risks, as subsequent surveys may be subject to different survey conditions, marine mammal behaviour and survey methodology (Cañadas *et al.* 2004). In an ideal world, the use of independent observers to estimate $g(0)$ on marine mammal surveys should be implemented wherever, and whenever possible. Only then will conservation and management planners reveal the true status of the marine mammals they are trying to protect. An unbiased understanding of the status of marine mammals in MPAs will not only shed light on the success or failure of management stratergies, but improve the conservation hopes of each species and their habitat.

5. REFERENCES

Barlow, J. (1988). Harbour porpoise, *Phocoena Phocoena,* abundance estimation for California, Oregon, and Washington: I. Ship surveys. *Fisheries Bulletin,* **86(3)**: 417-432.

Barlow, J., Oliver, C. W., Jackson, T. D. and Taylor, B. L. (1988b). Harbour porpoise, *Phocoena Phocoena,* abundance estimation for California, Oregon, and Washington: II. Aerial surveys. *Fisheries Bulletin,* **86(3)**: 433-444.

Barlow, J., Gerrodette, T. and Sibler, G. (1997). First estimates of vaquita abundance. *Marine Mammal Science,* **13(1)**: 44-58.

Barlow, J., Gerrodette, T. and Forcada, J. (2001). Factors affecting perpendicular sighting distances on shipboard line-transect surveys for cetaceans. *Journal of Cetacean Management and Research,* **3(2):** 201-212.

Beavers, S. C. and Ramsey, F. L. (1998). Detectability analysis in transect surveys. *Journal of Wildlife Management,* **62(3)**: 948-957.

Beck, C. A., Bowen, W. D., McMillan, J. I. and Iverson, S. J. (2003). Sex differences in the diving behaviour of a size-dimorphic capital breeder: The grey seal. *Animal Behaviour,* **64**: 1-13.

Berrow, S. D., O'Neill, M. and Brogan, D. (1998). Discarding practices and marine mammal by-catch in the Celtic Sea herring fishery. *Biology and the Environment: Proceedings of the Royal Irish Academy,* **98(1)B:** 1-8.

Bjørge, A. and Tolley, K. A. (2002). Harbour porpoise *Phocoena Phocoena. In* Perrin, W. F., Würsig, B. and Thewissen, J. G. M. (eds). *Encyclopedia of Marine Mammals.* pp.549-551. Academic Press.

Blanco, C., Salomón, O. and Raga, J. A. (2001). Diet of bottlenose dolphin (*Tusiops truncatus)* in the western Mediterranean Sea. *Journal of the Marine Biological Association of the U.K.*, **81:** 1053-1058.

Borchers, D. L., Zucchini, W. and Fewster, R. M. (1998a). Mark-recapture models for line transect surveys. *Biometrics,* **54**: 1207-1220.

Borchers, D. L., Buckland, S. T., Goedhart, P. W., Clarke, E. D. and Hedley, S. L. (1998b). Horvitz-Thompson estimators for double-platform line transect surveys. *Biometrics,* **54**: 1221-1237.

Borchers, D. L. (2005). Estimating detection probability from line-transect cetacean surveys when detection on the line is not certain: An overview. *In* Thomsen, F., Urgate, F. and Evans, P. G. H. (eds). *Proceedings of the workshop on: Estimation of g(0) in line-transect surveys of cetaceans. European Cetacean Society's 18th Annual Conference 2004.* pp. 4-11.

Bosetti, V. and Pearce, D. (2003). A study of environmental conflict: The economic value of grey seals in Southwest England. *Biodiversity and Conservation,* **12**: 2361-2392.

Bristow, T. (2004). Changes in coastal site usage by bottlenose dolphins (*Tursiops truncatus)* in Cardigan Bay, Wales. *Aquatic Mammals,* **30(3)**: 398-404.

Buckland, S. T. and Turnock, B. J. (1992). A robust line transect method. *Biometrics,* **48**: 901-909.

Buckland, S. T., Goudie, I. B. J. and Borchers, D. L. (2000). Wildlife population assessment: Past developments and future directions. *Biometrics,* **56**: 1-12.

Buckland, S. T., Anderson, D. R., Burnham. K. P., Laake, J. L., Borchers, D. L. and Thomas, L. (2001). Introduction to Distance Sampling: Estimating abundance of biological populations. Oxford University Press Inc. New York. 432p.

Buckland, S. T., Anderson, D. R., Burnham. K. P., Laake, J. L., Borchers, D. L. and Thomas, L. (2004). Advanced Distance Sampling: Estimating abundance of biological populations. Oxford University Press Inc. New York. 416p.

Burnham, K. P. and Anderson, D. R. (1974). Mathematical models for nonparametric inferences from line transect data. *Biometrics,* **32**: 325-336.

Calambokidis, J. (1998). Vessel surveys for harbour porpoise off the Washington coast. *In* Kajimura, H. (eds). *Harbour porpoise interactions with Makah salmon set net fishery in coastal Washington waters, 1988-89.* NOAA technical report.

Cañadas, A., Desportes, G. and Borchers, D. L. (2004). The estimation of the detection function $g(0)$ for short-beaked common dolphins (*Delphinus delphis*), using double-platform data collected during the NASS-95 Faroese survey. *Journal of Cetacean Research and Management,* **6(2)**: 191-198.

Carretta, J. V., Forney, K. A. and Laake, J. L. (1998). Abundance of southern California bottlenose dolphins estimated from tandem aerial surveys. *Marine Mammal Science,* **14(4)**: 655-675.

Carretta, J. V., Taylor, B. L. and Chivers, B. L. (2000). Abundance and depth distribution of the harbour porpoise (*Phocoena phocoena*) in northern California determined from a 1995 ship survey. *Fisheries Bulletin,* **99**: 29-39.

Ceredigion County Council, Countryside Council for Wales, Environment Agency Wales, North Western and North Wales Sea Fisheries Committee, Pembrokeshire Coast National Park Authority, Pembrokeshire County Council, South Wales Sea Fisheries Committee, Trinity House, and Dŵr Cymru Welsh Water (2001). Cardigan Bay Special Area of Conservation management plan. http://www.ceredigion.gov.uk/cbsac/. 213p.

Cockcroft, V. G. and Ross, G. J. B. (1990). Age, growth, and reproduction of bottlenose dolphins *Tursiops truncatus* from the east coast of southern Africa. *Fisheries Bulletin,* **88(2)**: 189-202.

Conner, R. C., Wells., R. S., Mann, J. and Read, A. J. (2000). The bottlenose dolphin: Social relationships in a fission-fusion society. *In* Mann, J., Conner, R. C., Tyack, P. L. and Whitehead, H. (eds). *Cetacean Soceties: Field studies of whales and dolphins.* University of Chicago Press. Pp. 91-126.

Conner, R. C., Heithaus, M. R. and Barre, L. M. (2001). Complex social structure, alliance stability and mating access in a bottlenose dolphin 'super-alliance'. *Proceedings of the Royal Society of London, Series B,* **268**: 263-267.

Constantine, R., Brunton, D. H. and Dennis, T. (2004). Dolphin watching tour boats change bottlenose dolphin (*Tursiops truncatus*) behaviour. *Biological Conservation,* **117**: 299-307.

Countryside Council for Wales (2005). Cardigan Bay European Marine Site. Countryside Council for Wales' advice given under Regulation 33(2) of the Conservation (Natural Habitats &c.) Regulations 1994. 125p.

Cresswell, G. and Walker, D. H. (2001). Whales and dolphins of the European Atlantic, the Bay of Biscay and the English Channel. *Wild Guides Ltd.* 55p.

de Boer, M. N. and Simmonds, M. P. (2003). Small cetaceans along the coasts of Wales and Southwest England. *WDCS/Greenpeace Survey Report.* 43p.

Directive (92/43/EEC) on the Conservation of Natural Habitats and of Wild Fauna and Flora. OJ L 206. 22.7.1992.

Evans, P. G. H. and Hammond, P. S. (2004). Monitoring cetaceans in European waters. *Mammal Review,* **34(1)**: 131-156

Fontaine, P. M., Hammill, M. O., Barrette, C. and Kingsley, M. C. (1994). Summer diet of the harbour porpoise (*Phocoena phocoena*) in the estuary and the northern Gulf of St. Lawrence. *Canadian Journal of Fisheries and Aquatic Sciences,* **51(1)**: 172-178.

Gerrodette, T. and Forcada, J. (2002). Estimates of abundance of northeastern offshore spotted, coastal spotted, and eastern spinner dolphins in the eastern tropical Pacific Ocean. *Southwest Fisheries Science Centre Administrative Report LJ-02-06,* 41p.

Gordon, J. (2001). Measuring the range to animals at sea from boats using photographic and video images. *Journal of Applied Ecology,* **38**: 879-887.

Grellier, K., Arnold, H., Thompson, P., Wilson, B., and Curran, S. (1995). Management recommendations for the Cardigan Bay bottlenose dolphin population. *Report to Countryside Council for Wales* (*CCW Science Report 134*). 68 pp.

Hall, A., McConnell, B. J. and Baker, R. J. (2001). Factors affecting first-year survival in grey seals and their implications for life history strategy, *Journal of Animal Ecology,* **70(1)**: 138-147.

Hall, A. (2002). Gray seal *Halichoerus grypus. In* Perrin, W. F., Würsig, B. and Thewissen, J. G. M. (eds). *Encyclopedia of Marine Mammals.* pp.522-524. Academic Press.

Hammond, P. S., Hall, A. J. and Prime. J. H. (1994a). The diet of grey seals around Orkney and other island and mainland sites in north-eastern Scotland. *Journal of Applied Ecology,* **31:** 340-350.

Hammond, P. S., Hall, A. J. and Prime. J. H. (1994b). The diet of grey seals in the Inner and Outer Hebrides. *Journal of Applied Ecology,* **31:** 737-746.

Hammond, P. S., Berggren, P., Benke, H., Borchers, D. L., Collet, A., Heide-Jørgensen, M. P., Heimlich, S., Hiby, A. R., Leoplod, M. F. and Øien, N. (2002). Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. *Journal of Applied Ecology,* **39**: 361-376.

Hastie, G. D., Wilson, B., Tufft, L. H. and Thompson, P. M., (2003). Bottlenose dolphins increase breathing synchrony in response to boat traffic. *Marine Mammal Science* **19**: 74–84.

Hooker, S. K. and Gerber, L. R. (2004). Marine reserved as a tool for ecosystem-based management. *Bioscience,* **54(1):** 27-39.

Hoyt, E. (2005). Marine protected areas for whales, dolphins and porpoises: A handbook for cetacean habitat conservation. Earthscan. 492p.

Jaramillo-Legorreta, A. M., Rojas-Bracho, A. and Gerrodette, T. (1999). A new abundance estimate for vaquitas: First step for recovery. *Marine Mammal Science,* **15(4)**: 957-973.

Jones, N. H. (2004). Abundance and distribution of harbour porpoise (*Phocoena phocoena*) in North Anglesey waters. *MSc Thesis, University of Wales, Bangor.*

Laake, J. L., Calambokdis, J., Osmek, S. D. and Rugh, D. J. (1997). Probability of detecting harbour porpoise from aerial surveys: Estimating *g*(0). *Journal of Wildlife Management,* **61(1):** 63-75.

Laake, J. L. (1999). Distance sampling with independent observers: Reducing bias from heterogeneity by weakening conditional independence assumption. *In* Garner, G. W., Amstrup, S. C., Laake, J. L., Manly. B. F. J., McDonald, L. L. and Robertson, D. G. (eds). *Marine Mammal Survey and Assessment Methods.* pp.137-148. A. A. Balkema, Rotterdam.

Law, R. J., Allchin, C. R. and Morris, R. J. (1995). Uptake of Organochlorines (Chlorobithenyls, Dieldrin, Tital PCB & DDT) in bottlenose dolphin *Tursiops truncatus* from Cardigan Bay, West Wales. *Chemosphere,* **30(3)**: 547-560.

Lasseau, D., Schnieder, K., Boisseau, O. J., Haase, P., Slooten, S. and Dawsen, S. M. (2003). The bottlenose dolphin community of Doubtful Sound features a large proportion of long-lasting associations. Can geographic isolation explain this unique trait? *Behavioural Ecology and Sociobiology,* **54(4)*:*** 396-405.

Lewis, T. (2005). Estimation of *g*(0) in line-transect surveys of cetaceans- Acoustics: IFAW's towed array system. *In* Thomsen, F., Urgate, F. and Evans, P. G. H. (eds). *Proceedings of the workshop on: Estimation of g(0) in line-transect surveys of cetaceans. European Cetacean Society's 18th Annual Conference 2004.* pp. 38-44.

Marsh, H. and Sinclair, D. F. (1989). Correcting for visibility bias in strip transect aerial surveys of aquatic fauna. *Journal of Wildlife Management,* **53**: 1017-1024.

Mate, B. R., Rossbach, K. A., Nieukirk, S. L., Wells, R. S., Irvine, A. B., Scott, M. B. and Read, A. J. (1995). Satellite movemnetss and dive behaviour of bottlenose dolphin (*Tursiops truncatus*) in Tampa Bay, Florida. *Marine Mammal science,* **11(4)**: 452-463.

Möller, L. M., Beheregaray, L. B., Harcourt, R. G., Krützen, M. (2001). Alliance membership and kinship in wild male bottlenose dolphins (*Tursiops aduncus*) of southeastern Australia. *Proceedings of the Royal Society of London, Series B,* **268**: 1941-1947.

Morris, R. J., Law, R. J., Allchin, C. R., Kelly, C. A., and Fileman, C. F. (1989). Metals and Organochlorines in Dolphins and Porpoises of Cardigan Bay, West Wales. *Marine Pollution Bulletin,* **20(10)**: 512-523.

Okamura, H., Kitakado, T., Hiramatsu, K. and Mori, M. (2003). Abundance estimation of diving animals by the double platform line transect method. *Biometrics,* **59**: 512-520.

Palka, D. L. (1996). The effect of Beaufort sea state on the sightability of harbour porpoise in the Gulf of Maine. *Report to the International Whaling Commision,* **46**: 575-582.

Palka, D. L. (2000). Abundance of the Gulf of Maine/Bay of Fundy harbour porpoise based on shipboard and aerial surveys during 1999. *Northeast Fisheries Science Center Reference Document 00-07.* 35p.

Palka, D. L. and Hammond, P. S. (2001). Accounting for responsive movement in line transect estimates of abundance. *Canadian Journal of Fisheries and Aquatic Science,* **58**: 777-787.

Palka, D. L. (2005a). Aerial surveys of the Northwest Atlantic: Estimation of *g(0). In* Thomsen, F., Urgate, F. and Evans, P. G. H. (eds). *Proceedings of the workshop on: Estimation of g(0) in line-transect surveys of cetaceans. European Cetacean Society's 18th Annual Conference 2004.* pp. 12-17.

Palka, D. L. (2005b). Shipboard surveys of the Northwest Atlantic: Estimation of *g(0). In* Thomsen, F., Urgate, F. and Evans, P. G. H. (eds). *Proceedings of the workshop on: Estimation of g(0) in line-transect surveys of cetaceans. European Cetacean Society's 18th Annual Conference 2004.* pp. 32-37.

Patterson, I. A. P., Reid, R. J., Wilson, B., Grellier, K., Ross, H. M. and Thompson, P. M. (1998). Evidence for infanticide in bottlenose dolphins: An explanation for violent interactions with harbour porpoises? *Proceedings of the Royal Society of London, Series B,* **267**: 1167-1170.

Pierpoint, C. and Allan, L. (2004). Bottlenose dolphins and boat traffic on the Ceredigion Marine Heritage Coast, West Wales. *Ceredigion County Council report.* 44p.

Read, A. J. and Holn, A. A. (1995). Life in the fast lane: The life history of harbour porpoises in the Gulf of Maine. *Marine Mammal Science,* **11(4)**: 423-440.

Santos, M. B., Pierce, G. J., Reid, R. J., Patterson, I. A. P., Ross, H. M. and Mente, E. (2001). Stomach contents of bottlenose dolphins (*Tursiops truncatus*) in Scottish waters. *Journal of the Marine Biological Association of the U. K,* **81**: 873-878.

Schweder, T., Skaug, H. J., Langaas, M. and Dimakos, X. K. (1999). Simulated - likelihood methods for complex double-platform line transect surveys. *Biometrics,* **55**: 678-687.

Shane, S. H., Wells, R. S. and Würsig, B. (1986). Ecology, behaviour and social organisation of the bottlenose dolphin: A review. *Marine Mammal Science,* **2(1)**: 34-63.

Scheidat, M., Gilles, A. and Siebert, U. (2005). Applying the circle-back method to estimate *g*(0) – Experiences and results from aerial surveys in German waters. *In* Thomsen, F., Urgate, F. and Evans, P. G. H. (eds). *Proceedings of the workshop on: Estimation of g(0) in line-transect surveys of cetaceans. European Cetacean Society's 18th Annual Conference 2004.* pp. 18-24.

Smith, A. J. and Read, A. J. (1992). Consumption of euphausiids by harbour porpoise (*Phocoena phocoena)* calves in the Bay of Fundy. *Canadian Journal of Zoology,* **70**: 1629-1632.

Tregenza, N. J. C., Berrow, S. D., Hammond, P. S. and Leaper, R. (1997). Harbour porpoise (*Phocoena phocoena* L.) by-catch in set gillnets in the Celtic Sea. *ICES Journal of Marine Science,* **54**: 896-904.

Turnock, B. J. and Quinn, T. J. (1991). The effect of responsive movement on abundance estimation using line transect sampling. *Biometrics,* **47**: 701-715.

Walker, J. L., Potter, C. W., and Macko, S. A. (1999). The diets of modern and historic bottlenose dolphin populations reflected through stable isotopes. *Marine Mammal Science,* 15(2): 335-350.

Walten, M. J. (1997). Population structure of harbour porpoise *Phocoena phocoean* in the seas around the UK and adjacent waters. *Proceedings of the Royal Society of London, Series B,* **264**:89-94.

Wells, R. S. and Scott, M. D. (2002). Bottlenose dolphins: *Tursiops truncatus* and *T. aduncus. In* Perrin, W. F., Würsig, B. and Thewissen, J. G. M. (eds). *Encyclopedia of Marine Mammals.* pp.122-128. Academic Press.

Westgate, A. J., Read, A. J., Berggren, P., Koopman, H. N. and Gaskin, D. E. (1995). Diving behaviour of harbour porpoises, *Phocoena phocoena. Canadian Journal of Fisheries and Aquatic Sciences.* **52**: 1064-1073.

Wilson, B., Reid, R. J., Grellier, K., Thompson, P. M. and Hammond, P. S. (2004) Considering the temporal when managing the spatial: A population range expansion impacts protected areas-based management for bottlenose dolphins. *Animal Conservation,* **7**: 331-338.

Würsig, B. and Würsig, H. F. (1977). The photographic determination of group size, composition, and stability of coastal porpoises (Tursiops truncatus). *Science,* **198**: 755-756.

Websites

www.cardiganbaysac.org.uk
www.ukmarinesac.org.uk
www.seawatchfoundation.org.uk
www.bbc.co.uk

6. *APPENDICIES*

6.1 APPENDIX A

Effort form

Boat: __________________ Person responsible for data: __________Crew:____________________________________ Page _____of _____

Date:___________________ Time start: ___________ Time end: ___________ Type of trip: TR ☐ NTR ☐

Leg	Time	Lat.	Long.	Speed	Course	Effort type		Precipitation				Visibility (km)	Sea state		Sightings ref.	Stratum & comments
								Type		Int.			B	S		
S C E		N52°	W004°			CW	DS	N	R	I	L M	0-1__ 1-10__ >10__				
						LT	ID	F		C	H					
S C E		N52°	W004°			CW	DS	N	R	I	L M	0-1 __ 1-10__ >10__				
						LT	ID	F		C	H					
S C E		N52°	W004°			CW	DS	N	R	I	L M	0-1 __ 1-10__ >10__				
						LT	ID	F		C	H					
S C E		N52°	W004°			CW	DS	N	R	I	L M	0-1 __ 1-10__ >10__				
						LT	ID	F		C	H					
S C E		N52°	W004°			CW	DS	N	R	I	L M	0-1 __ 1-10__ >10__				
						LT	ID	F		C	H					
S C E		N52°	W004°			CW	DS	N	R	I	L M	0-1 __ 1-10__ >10__				
						LT	ID	F		C	H					

Figure 1a: Effort form used aboard the ship board surveys of Cardigan Bay SAC to record the ships course, speed, environmental variables and any subsequent sightings

Sightings Form

Date:________________ Type of trip: TR ☐ NT ☐ Page:___of___

S	Time	Lat	Long	Dir. Ang.	Dist.	Species		Total no.	A	J	C	N B	Cue	Effort type		Sea state		Beh	Reac. to Boat		Seen by
																B	S	Dir.			
_1		N52º	W004º	P - S		D	HP							CW	DS				A	T	
						S								LT	ID				U		
_2		N52º	W004º	P - S		D	HP							CW	DS				A	T	
						S								LT	ID				U		
_3		N52º	W004º	P - S		D	HP							CW	DS				A	T	
						S								LT	ID				U		
_4		N52º	W004º	P - S		D	HP							CW	DS				A	T	
						S								LT	ID				U		
_5		N52º	W004º	P - S		D	HP							CW	DS				A	T	
						S								LT	ID				U		
_6		N52º	W004º	P - S		D	HP							CW	DS				A	T	
						S								LT	ID				U		
_7		N52º	W004º	P - S		D	HP							CW	DS				A	T	
						S								LT	ID				U		
_8		N52º	W004º	P - S		D	HP							CW	DS				A	T	
						S								LT	ID				U		

Figure 2a: Sightings form used to by the primary observers to record the details of each sighting

Independent Observer Sightings Form

Date:________________ Type of trip: TR ☐ NTR ☐ Page:___of___

IO no	**Time**	**Lat**	**Long**	**Dir. Ang.**	**Dist.**	**Species**		**Total no.**	**Cue**	**Effort type**		**Sea state**		**Seen by observers on roof?**		**If yes, Sighting no.**	**Seen by**	**Comments**
												B	**S**					
_1		N52°	W004°	P - S		D	HP			LT	DS			Y	N			
						S												
_2		N52°	W004°	P - S		D	HP			LT	DS			Y	N			
						S												
_3		N52°	W004°	P - S		D	HP			LT	DS			Y	N			
						S												
_4		N52°	W004°	P - S		D	HP			LT	DS			Y	N			
						S												
_5		N52°	W004°	P - S		D	HP			LT	DS			Y	N			
						S												
_6		N52°	W004°	P - S		D	HP			LT	DS			Y	N			
						S												
_7		N52°	W004°	P - S		D	HP			LT	DS			Y	N			
						S												

Figure 3a: The sightings form used by the Independent Observers to record any sightings made by the IO platform.

6.3 APPENDIX B

Region (km2)	Transect	Perp distance	Cluster size	object	observer	detected	Sea state	Year
958.6	2.314							
	0.673	101.811	3	1	1	1	0	0
		101.811	3	1	2	0	0	0
	3.252	61.643	3	2	1	1	0	0
		61.643	3	2	2	0	0	0
	3.456							
	2.545							
	1.180							
	2.977	134.919	1	3	1	1	0	0
		134.919	1	3	2	0	0	0
	3.832							
	2.695							
	0.550							
	1.369	310.186	2	4	1	1	0	0
		310.186	2	4	2	0	0	0
	1.395							
	1.027							
	4.036	68.68	2	45	1	1	0	0
	4.036	68.68	2	45	2	1	0	0
	0.798	342.500	3	5	1	1	0	0
		342.500	3	5	2	0	0	0
	1.064							
	0.011							
	5.271							
	7.670							
	0.945							
	1.336							
	1.231	464.932	2	6	1	1	0	0
		464.932	2	6	2	0	0	0
	0.395							
	5.463							
	1.900	310.186	1	7	1	1	1	0
		310.186	1	7	2	0	1	0
	1.511							
	0.808	263.386	3	8	1	1	1	0
		263.386	3	8	2	0	1	0
		441.470	2	46	1	1	1	0
		441.470	2	46	2	1	1	0
		412.090	2	47	1	1	1	0
		412.090	2	47	2	1	1	0

Figure 1b: Section of an Excel spreadsheet showing how data was formatted prior to importing into programme DISTANCE 5.0. Region corresponds to the total area of Cardigan Bay SAC. Se methods for full description of what each column means

6.3 APPENDIX C

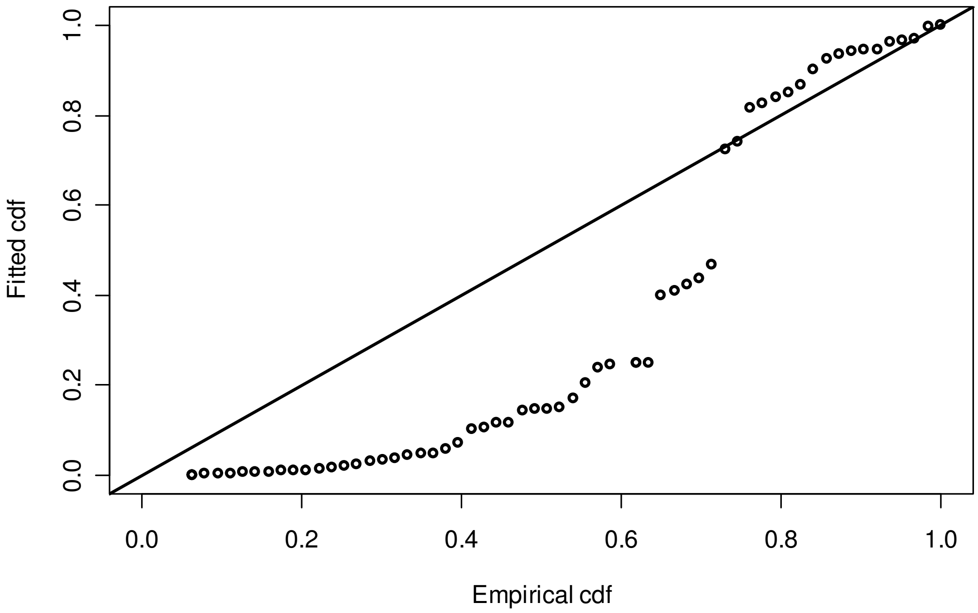

Figure 1c: Qq-plot of the cumulative detection function (cdf) against the empirical detection function (edf) of bottlenose dolphin distribution during line transect surveys in the Cardigan Bay SAC during 2003-2004.

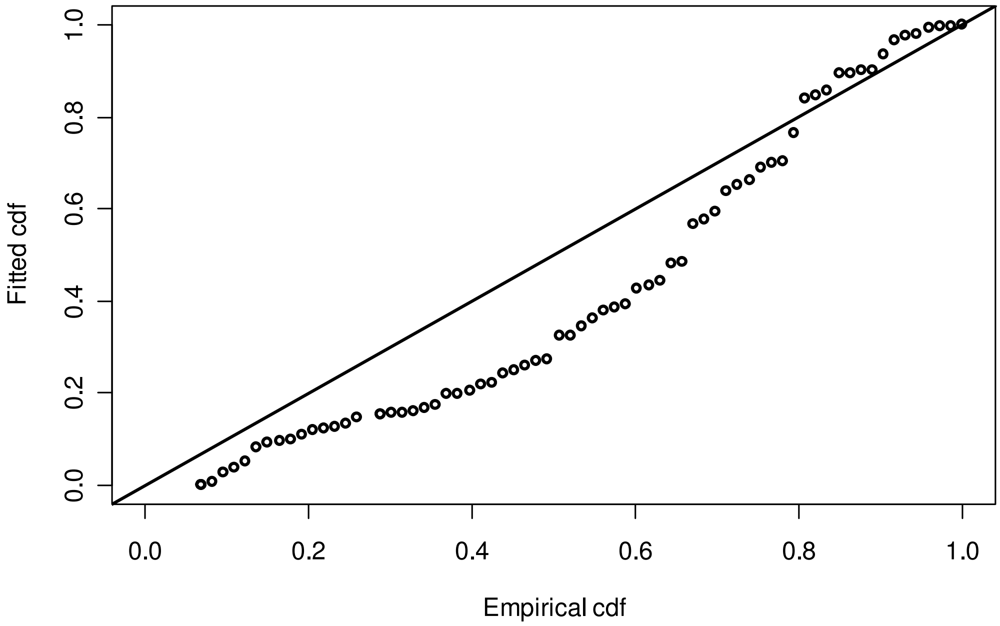

Figure 2c: Qq-plot of the cumulative detection function (cdf) against the empirical detection function (edf) of bottlenose dolphin distribution during line transect surveys in the Cardigan Bay SAC during 2005.

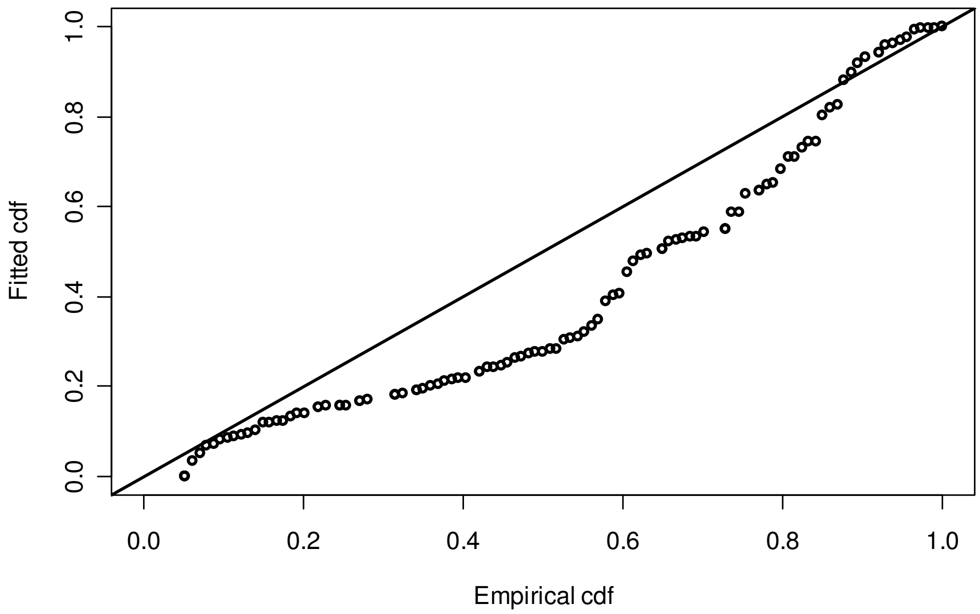

Figure 3c: Qq-plot of the cumulative detection function (cdf) against the empirical detection function (edf) of grey seal distribution during line transect surveys in the Cardigan Bay SAC during 2003-2004.

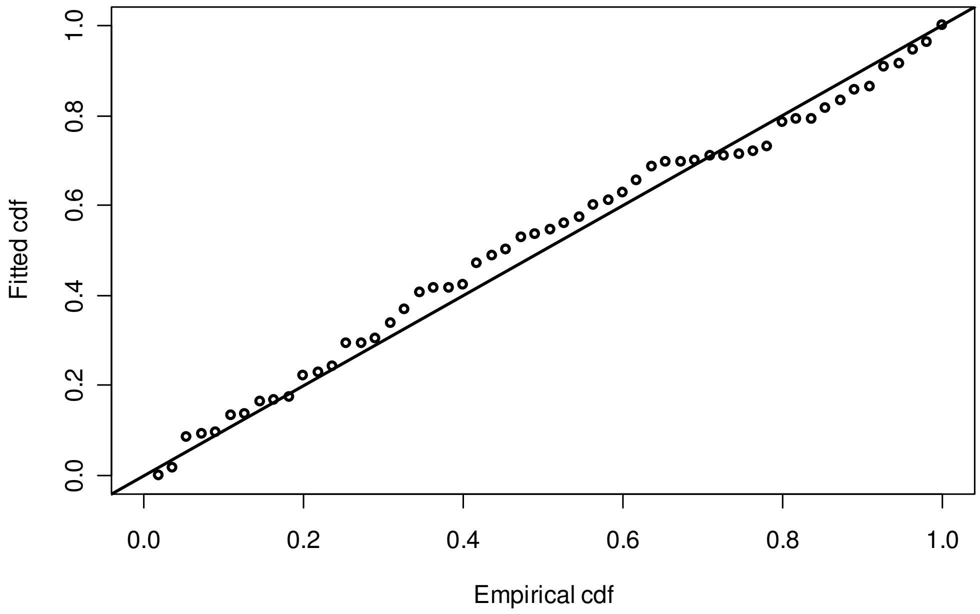

Figure 4c: Qq-plot of the cumulative detection function (cdf) against the empirical detection function (edf) of grey seal distribution during line transect surveys in the Cardigan Bay SAC during 2005.

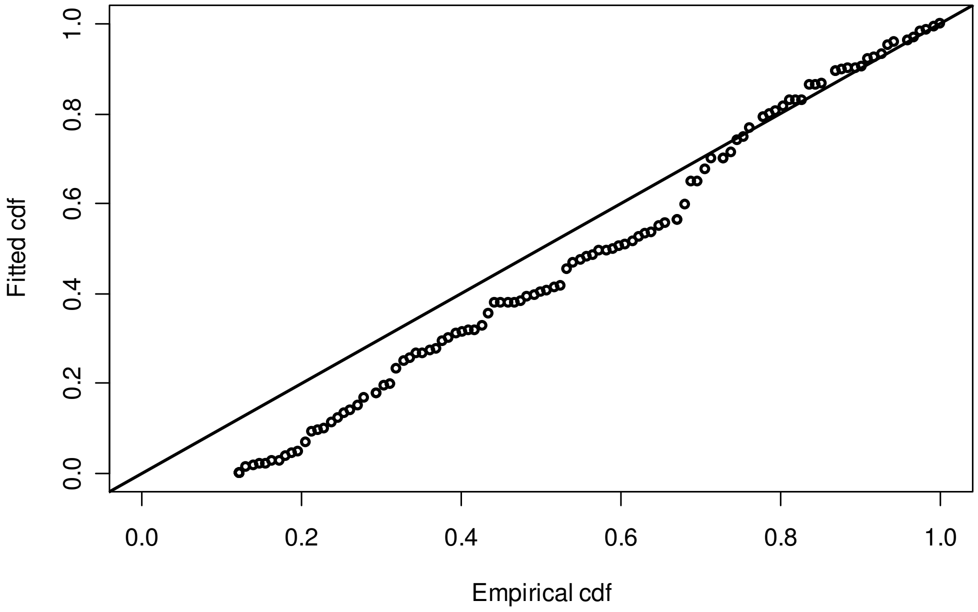

Figure 5c: Qq-plot of the cumulative detection function (cdf) against the empirical detection function (edf) of harbour porpoise distribution during line transect surveys in the Cardigan Bay SAC during 2003-2004.

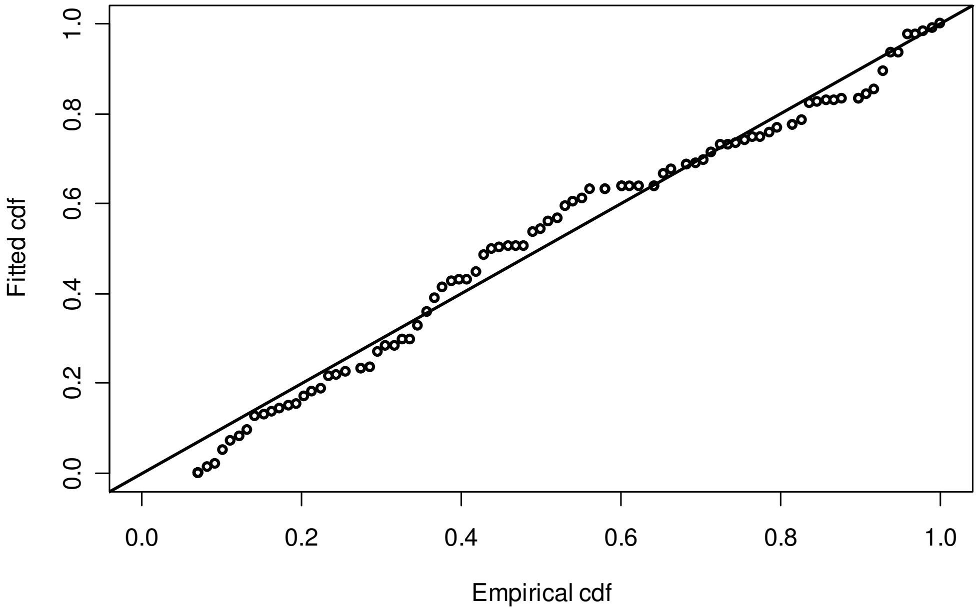

Figure 6c: Qq-plot of the cumulative detection function (cdf) against the empirical detection function (edf) of harbour porpoise distribution during line transect surveys in the Cardigan Bay SAC during 2005.