An updated population status report for bottlenose dolphins using the Lower River Shannon SAC in 2008

Final report to the National Parks and Wildlife Service

University College Cork
November 2008

Anneli Englund [1, 2], Simon Ingram [1, 2, *] and Emer Rogan [1]

1. Department of Zoology, Animal Ecology and Plant Sciences, University College Cork, Ireland
2. Coastal and Marine Resources Centre, Environmental Research Institute, University College Cork, Ireland
**Current address:* School of Earth, Ocean & Environmental Sciences, University of Plymouth, UK

Contents

Appendix: A compact disc accompanies this report, containing geo-referenced images of all animals identified during the project.

Executive Summary

Standardised boat surveys and photo-identification of individual bottlenose dolphins were used to estimate the abundance of bottlenose dolphins (*Tursiops truncatus*) using the Lower River Shannon SAC. A total of 11 surveys were conducted between June 14 and September 28 resulting in 22 encounters with bottlenose dolphin groups. Approximately 75 boat-hours were spent surveying the SAC with 21 hours spent during encounters with dolphins.

In total, 1,992 dorsal fin photographs were taken during surveys resulting in 215 identifications of 80 uniquely marked dolphins. Of these, 68 individuals were matched with a catalogue maintained by UCC since 1996 (Ingram, 2000; Ingram and Rogan, 2002; Englund *et al.,* 2007). In addition to animals identified during surveys conducted in previous years, 12 new individuals were added to the catalogue. Of all dolphins identified during 2008, 28 had permanent marks including fin nicks, 32 had superficial marks and 20 had temporary marks. School sizes ranged from 2 to 36 dolphins with a median school size of 6.5.

Photo identification data from eight completed surveys were used in a mark-recapture estimate of abundance. High quality images were selected of 53 well-marked individuals known from both left and right sides (approximately 66% of the dolphins encountered) for the mark-recapture model. Using a sightings matrix of this subset of animals the computer programme CAPTURE was used to calculate a maximum likelihood estimate of abundance of marked dolphins using the SAC during the survey period. We selected an estimator model tolerant of between-survey and between individual capture heterogeneity. The resulting estimate of marked dolphins was increased according to the calculated proportion of marked dolphins encountered during surveys. Using this procedure we estimate the number of dolphins using the Shannon SAC during June to September 2008 was 114 ± 16.9 (SE) dolphins (CV= 0.15, 95% CI 85-152). This estimate is less precise and lower than a previous estimate of 140 ±12 (SE) (CV =0.08 95% CI 125-174) calculated in 2006. Whilst a reduction in numbers of dolphins using the Shannon cannot be ruled out, the lower estimate is more likely attributable to lower sampling effort rather than a reflection of a true decline in numbers using the SAC. It is also important to note that the previous estimate of 140 lies well within the 95% CI of the latest estimate.

A new technique to use lasermetrics for estimations of body size was also tested, with some success. Photographs taken with lasers projected onto the fin or the body of the dolphin enabled correlations with previous measurements taken from stranded animals. The estimated body length of 5 individuals in the Shannon was calculated and was found to range from 282.7 to 315.8cm, well within the expected range for this species.

We also conducted a Population Viability Analysis to model the probability of extinction of this population in several hypothetical scenarios. We found the population unlikely to experience extinction over a 250year period in the absence of a major catastrophe. However, if the lower bounds of the abundance estimate are used (n = 85 individuals), the probability of extinction increases.

INTRODUCTION

Bottlenose dolphins (*Tursiops truncatus*) are widely distributed and inhabit temperate and tropical seas worldwide. They are often found in shallow, coastal habitats including inlets, bays, estuaries and rivers (Leatherwood and Reeves, 1983) and the Shannon Estuary represents a typical habitat for this species.

Their robust shape and relatively short beak makes bottlenose dolphins easily distinguished from other dolphin species found in Irish waters (Plate 1). Bottlenose dolphins are long-lived animals with an estimated life expectancy of about 50 years (Read *et al.,* 1993). They exhibit sexual dimorphism with adult males growing larger than females. Females reach sexual maturity around 10 years of age (Sergeant *et al.,* 1973) and newborn calves are about 1m in length following a 12-month gestation period (Leatherwood and Reeves, 1983).

Plate 1. A bottlenose dolphin photographed in the Shannon Estuary in 2008 displaying robust body shape, short beak, dark grey coloration and paler underside.

The Shannon Estuary is a critical habitat for bottlenose dolphins and is used by the largest resident population of this species in Irish waters (Ingram and Rogan, 2002). However, recent studies have indicated some degree of site fidelity by bottlenose dolphins at several other locations on the west coast, including the waters of Connemara, Co Galway; Cork Harbour and adjacent waters; Kenmare River and Brandon Bay, Co. Kerry; Donegal Bay and Broadhaven Bay, Co Mayo (Ingram *et al*., 2001; ÓCadhla *et al*., 2003; Ingram *et al*., 2003; Englund *et al.*, 2006).

Conservation status

Bottlenose dolphins are listed as Annex II species in the EU Habitats Directive and the Shannon Estuary is to date the only Special Area of Conservation (SAC) designated for this species in Irish waters. Bottlenose dolphins have a widespread but patchy distribution on European Atlantic coasts. The best documented adjacent populations are found in the Moray Firth, Scotland (Wilson *et al.,* 1999); Cardigan Bay, Wales (Arnold, 1993; Baines *et al*., 2002); Brittany and Normandy, France (Liret *et al*., 1998; Liret, 2001; Kiszka *et al*., 2004) and the Sado Estuary, Portugal (Dos Santos and Lacerda, 1987). Two SACs have so far been designated in the UK, one in the Moray Firth, Scotland, with a population of about 129 individuals (Wilson *et al*., 1999) and a second in Cardigan Bay, Wales with a population estimated (based on photo-id mark-recapture methods) at 126 individuals. (Pesante *et al*., 2008). It should also be noted that here are also small numbers of dolphins found outside the UK SAC's, for example on the West Coast of Scotland (Grellier and Wilson, 2003; Ingram unpublished data) and in Cornwall (Woods, 1998).

It is important for effective management and conservation to obtain precise information relating to population size and ranging patterns. This type of information is vital to detect trends in numbers, changes in distribution, use of habitat or the effects of human activities on the population. Information on spatial and temporal variation in abundance is also necessary to determine whether management actions are needed and to evaluate the effectiveness of any actions that are implemented (Evans and Hammond, 2004).

Bottlenose dolphins using industrially developed coastal waters such as the Shannon are particularly vulnerable to anthropogenic disturbance and to the degradation of their habitat. Threats may include industrial and agricultural pollutant contamination (O'Sullivan, 1984; Moscrop, 1993; Jepson *et al*., 1999; O'Shea, 1999, Pierce *et al*., 2008); disturbance from marine industrial activities (Richardson *et al*., 1985; Richardson *et al*., 1995; Evans and Nice, 1997); by-catch mortality (accidental entanglement in fishing gear) (Read *et al*., 2006); physical and acoustic disturbance from shipping (Au and Perryman, 1981; Acevedo, 1991) and disturbance from dolphin watching boat traffic (Kruse, 1991; Gordon *et al*., 1992; Blane and Jaakson, 1994; Corkeron, 1995; Lutkebohle, 1995; Janik and Thompson, 1996; Berrow and Holmes, 1999; Lusseau, 2005). The Shannon region is a major centre of industry including aluminium extraction and electricity generation with coal fired and oil fired stations located at Money Point and Tarbert. The Shannon catchment includes large areas of farmland and several tributary rivers providing potential sources of contamination of the Estuary.

Long term residency and site fidelity

The dataset compiled during the last 12 years shows long-term site fidelity and seasonal residency of dolphins using the Shannon Estuary (Ingram, 2000; Ingram and Rogan, 2002; Englund *et al.,* 2007). The majority of permanently marked dolphins identified during a census in 2006 had been known since the project began in 1996 (Englund *et al.,* 2007).

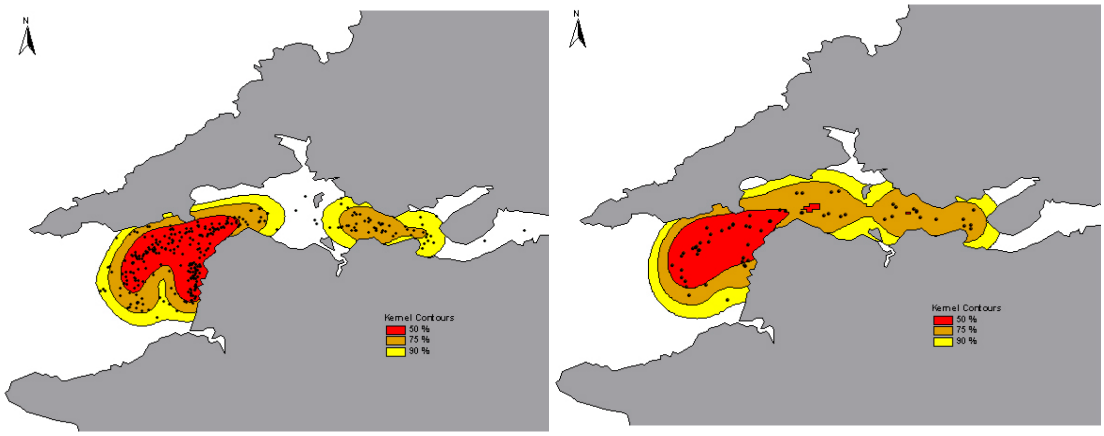
Abundance of the Shannon dolphin population

The abundance of dolphins using the Shannon SAC has previously been calculated using mark-recapture photo-identification techniques during three separate years; in 1997 (113 ±16 (SE), Ingram, 2000), in 2003 (121 ± 14 (SE), Ingram and Rogan, 2003) and most recently in 2006 (140 ± 12 (SE), Englund *et al.,* 2007). The work presented here includes an updated abundance estimate for the bottlenose dolphins of the Lower River Shannon using similar photo-id and mark-recapture methods.

Seasonal and temporal variation in habitat use

Year-round survey effort in previous years shows a repeated annual seasonal reduction in the number of dolphins using the Estuary during the winter months (Ingram, 2000; Englund *et al.*, 2007). The seasonal migration out of the Estuary during the winter months indicates that the Shannon SAC does not cover the entire home range of this population (Ingram *et al.,* 2001). Despite this seasonal migration we have found no differences in the distribution of encounters within the SAC during winter and summer months (Figure 1). Two critical areas within the Shannon Estuary were first identified in 2002 (Ingram and

Rogan, 2002) and in subsequent years data show these areas are important to dolphins year-round, year on year. The larger of these two areas is located at the estuary mouth near Kilcredaun and a smaller one off Money Point. There was a difference however, in the use of these two areas by individually identified dolphins with the known ranges of a minority of individuals extending into the up-river part of the study area (Figure 1).



a) **b)**

Figure 1. Kernel contour plots showing areas of concentrated use in the outer estuary from 1996 to 2007 during (a) summer months (May to September) (n=304); b) winter months (October to April) (n=64). Contours show the areas containing 90% (yellow), 75% (brown) and 50% (red) of all encounter locations. Black dots show encounter locations (from Englund *et al.*, 2007).

Population viability analysis

Small populations are more likely to go extinct than larger ones, underscored by the recent extinction of the baiji (*Lipotes vexillifer*), a freshwater dolphin endemic to the Yangtze River, China (Turvey *et al*., 2007). Small populations are also vulnerable to loss of genetic variability, the Allee effect and inbreeding depression (e.g. Ralls *et al*., 1988). In addition, they are susceptible to fluctuations in demographic stochasticity (changes in individual reproductive output, and mortality rates) and environmental stochasticity (such as disease outbreaks, harmful algal blooms or other environmental catastrophes). Models are therefore used to look at the viability of small and/or endangered populations given a number of different scenarios or hypothetical conditions (eg. Marmontel *et al*., 1997, Caswell *et al*., 1999, Thompson *et al*., 2000). Population viability analysis (PVA) is a method of modelling the long term projected stability of discrete populations in response to estimated reproductive parameters and simulated environmental effects. The models use an iterative approach to determine the probability that a population will go extinct within a given number of years. For many populations and species, PVA has proved vital in developing conservation plans and management strategies, elucidating factors which can lead to decline and help prioritise conservation objectives (e.g. Vargas *et al.,* 2007). PVA can also be used to model population viability under different management regimes (e.g. Thompson *et al*., 2000), and to predict, for example, how a species will recover if subjected to different levels of bycatch (e.g. Goldsworthy and Page, 2007).

PVA models are subject to a number of assumptions and while this approach has proved very useful for conservation managers, the models have invited considerable debate, especially due to the fact that many simple assumptions have to be made, which can affect the accuracy of the projection. Criticisms include lack of data for population parameters, lack of precision in population parameters and assumed population stationarity of population parameters (Patterson and Murray, 2008).

In this study, we used the results of our abundance estimate to model the probability of extinction of the Shannon dolphin population over a 250year period in a number of hypothetical scenarios.

Lasermetrics

The use of lasermetrics to examine morphometric features in wild animals has been used successfully on a number of species, including killer whales (*Orcinus orca*) by Durban and Parsons (2006) and bottlenose dolphins (Cheney *et al*., 2008). Data on morphometrics are central to our understanding of a number of key elements of population ecology, including individual and population growth rates and mating patterns. These measurements are difficult to obtain in the wild, and are often derived from stranded animals or live captures. Within the Shannon estuary, little is known about the age or size structure of the population and we carried out a feasibility study to determine the applicability of using lasermetrics to examine dorsal fin height.

Project aims

The main aims of this project were to:

- calculate an abundance estimate for bottlenose dolphins using the lower river Shannon SAC during 2008.
- use long term data to assess long term site fidelity and ranging patterns of individually identified animals.
- model population viability analysis (PVA) to examine the long term stability of the population.
- test a new technique of lasermetrics to estimate morphometric data.

METHODS

Boat based photo-identification surveys

Dedicated boat surveys for photo-identification were conducted using a 6m rigid hull inflatable boat (RIB) between June 14th and September 28th 2008. A minimum of eight full photo-identification surveys were contracted during the study period with a provision for two additional surveys to compensate for incomplete surveys abandoned due to poor weather conditions. A standardised 80km route (Figure 2) used by UCC for dolphin surveys in the Shannon Estuary since 1996 was followed at approximately $20kmh^{-1}$. Surveys were conducted in a Beaufort sea-state of three or less, with suitable light and swell conditions in order to minimise the effect of weather or sea conditions on the probability of sighting and photographing dolphins. If conditions deteriorated the survey was abandoned.

Survey methods and photographic analysis used have been thoroughly described in previous abundance reports to the NPWS by UCC (Ingram *et al.,* 2003; Englund *et al.,* 2007) but for clarity are also reproduced below.

During surveys, the route was followed until a group of dolphins were sighted. A dolphin school is defined here as all dolphins within a 100m radius of each other (Irvine *et al*., 1981) and hereafter encounters refer to periods of data collection with dolphin schools. Following a sighting, dolphins were approached slowly and attempts made to photograph all school members. Waypoints were recorded at the start of encounters using an onboard Global Positioning System (GPS). Additionally, the presence of juveniles, calves or neonates were noted. Boat movements and changes in speed was minimised in order to reduce any negative effects. The behaviour of dolphins towards the survey vessel was also monitored and any signs of distress or evasive behaviours from the animals recorded. If strong avoidance behaviours (e.g. aggressive approaches or rapid avoidance) were observed the survey team avoided approaching the animals within 50 meters for 5 minutes and terminated the encounter if such behaviours were repeated when the encounter was resumed.

Dolphin id photographs were taken perpendicular to the dorsal fin, preferably from within a distance of 20m, using an auto-focus digital SLR camera (Canon EOS 1D mark II) with a 70-200mm telephoto zoom lens. Each encounter continued until all animals had been photographed, preferably from both sides or until the school was lost (or if strong avoidance behaviours were noted as described above). Following an encounter the survey was resumed at the location of first sighting the animals and until the route was completed. Surveys on which the entire survey route was completed were classed as “full” and surveys that were incomplete due to deteriorating weather or light conditions were classed as “part”.

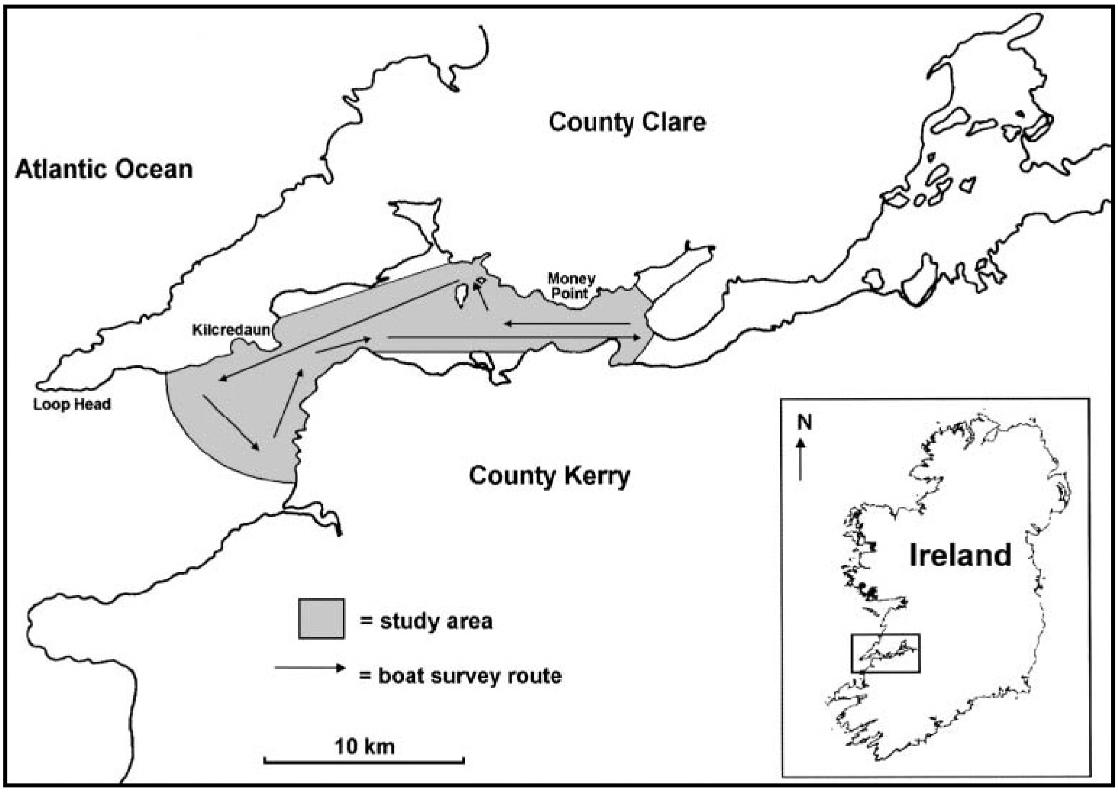


Figure 2. Map showing the study area and survey route.

Photograph analysis

The best photographs of each side of every dolphin identified from each encounter were selected from the downloaded images taken during each survey. The quality of these photographs was then scored for quality from 1 to 4 (see Table 1 for details) with no consideration to the degree of marking of the individual. Selected photographs were then matched with the archive catalogue of known dolphins maintained by UCC since 1996. When a match was made, the selected photographs were renamed with the appropriate catalogue number and added to the archive. If a match could not be found in the archive the animal was given a new catalogue number and subsequently added to the catalogue.

Table 1. The criteria used to score the quality of all photographs taken of dolphin dorsal fins (independent on degree of marking of individuals).

Grade	*Criteria*
1	Well lit and focused photo taken perpendicular to the dorsal fin at close range
2	More distant and less well lit or slightly angled photograph of the fin
3	Poorly lit or somewhat out of focused photograph, or photo taken at acute angles of the fin
4	Poorly focused, backlit or angled photographs taken at long distance to dolphins

Severity of identifying marks

A wide variety of identification marks are useful for identifying individual dolphins. These include permanent marks such as deep nicks on the trailing edge of the dorsal fin as well as other types of marks, which may or may not be permanent, such as fin shape, scratches or skin lesions on the dorsal fin or the flank of the dolphin. Some marks may last for several years and thus remain useful for long-term identification of an individual. Animals acquire marks with time and younger animals are added to the catalogue of known individuals as they gain distinguishing scars or nicks. Long term dedicated survey effort is required to ensure that individuals' changing marks are recorded correctly.

In this study, each catalogued dolphin was scored from 1 to 3 according to the severity of its natural markings (Plate 2). Dolphins with deep wounds and significant fin damage were considered permanently marked and assigned as grade 1 (Plate 1a). Dolphins with minor fin damage and/or deep tooth rakes were assigned as grade 2 (Plate 1b). Dolphins with superficial scratches and skin lesions were assigned as grade 3 (Plate 1c).

a) **b)** **c)**

Plate 2. Examples of dolphin fins photographed in 2008 showing the three grades of mark severity used in analysis. Each dolphin was graded from one to three as follows: a) grade 1 marks, consisting of significant fin damage or deep scarring that were considered permanent; b) temporary, grade 2 marking that consist of deep tooth rakes and lesions, with only minor cuts present; c) fin with grade 3 marks, having superficial rakes and lesions.

Site fidelity and long term ranging behaviour of individuals

We examined the year of first identification of all permanently marked dolphins encountered in 2008 in order to investigate long term site fidelity in the SAC. To examine long term patterns in the fine scale ranging behaviour of individual dolphins we compared the geographic distribution of sightings of dolphins encountered during 2008 with previous sightings data maintained since 1996.

Capture-recapture abundance analysis

Photo-identification data were used to model dolphin abundance in the Shannon using model Mth bundled within the 'mark-recapture' software CAPTURE (Rexsted and Burnham, 1991). Such multiple sample capture-recapture estimates depend on the following assumptions (Otis *et al*., 1978; Seber, 1982):

1. the population is closed for the duration of sampling
2. animals do not lose their identifying marks during the sampling period
3. all marks are correctly recorded in each capture (sighting)
4. each animal has an equal and constant 'capture' probability

The first assumption refers to the geographic and demographic closure (The Shannon Estuary) in which there is no immigration or emigration into or out of the population or changes due to birth or death or change of marking during the period of sampling. The short duration of the sampling period (June to September) included in the analysis effectively ensured population closure during sampling.

Using identifications based on animals' natural markings risks violating assumptions 2 and 3 because of the differences in the severity of markings between individuals, making some members of a population more easily recognised than others (Gunnlaugsson and Sigurjonsson, 1990). Additionally, incorrect matches may result from poor photographic quality or comparison of insufficiently marked individuals. In order to reduce the likelihood of such matching errors, poor quality photographs (lower score than 3) and poorly marked grade 3 animals (see Plate 2) were excluded from capture-recapture analysis.

Only dolphins known from both their left and right sides were included in the mar-recapture analysis in order to avoid over inflating the sampled population through false identifications. In previous years, separate left and right estimates were calculated and then combined to give an averaged estimate. However, due to the reduction in survey effort commissioned during 2008, identifications of well marked dolphins from either side were pooled in order to increase individual capture rates of sampled dolphins.

Consequently, the dolphins included in the mark-recapture analysis represent a 'marked' subset of the animals using the SAC. Each individual included in the subset is considered sufficiently marked to enable identification from all the selected photographs of either side of the dorsal fin.

Proportion of marked dolphins

Since the data set used for the estimate is restricted to well-marked animals and does not include poorly marked individuals, the capture estimates were inflated according to the proportion of marked animals in the population. All identifications were examined in order to derive the proportion of dolphins that belonged to the marked subset used in the 'mark-recapture' analysis. This proportion was calculated by comparing the total number of identifications of all dolphins with the number of identifications of dolphins from the marked subset (after Wilson *et al*., 1999). The following formula was used to increase the estimates according the proportion of marked animals in the population:

$$N = \frac{N\text{hat}}{\theta}$$

where; N = estimated total population size, Nhat = estimate of the subset of marked animals, θ (theta) = proportion of the population with identifiable markings.

The variance of the total estimate (varN) was obtained using the delta method as follows:

$$\text{varN} = N^2 \times \frac{\text{varNhat}}{Nhat^2} + \frac{1-\theta}{n\,\theta}$$

Population viability analysis

We used VORTEX (version 9.92. Lacy, 1993) to carry out a range of simulations under a number of scenarios. In two models the point estimate derived from the 2008 mark-recapture analysis was used as the initial population size (114 dolphins). We ran the model allowing zero or one catastrophe (1% of years) using a 250year timeframe and 1000 iterations, in increments of one year. We also ran two simulations (with one and zero catastrophes) with a start population of 85 individuals, the lower bound of the CI for the 2008 estimate. In these simulations, extinction was defined as occurring when 10 individuals remained.

Despite the long-term nature of this study, there are sufficient gaps in the data (years and/or months missing) to prevent us from deriving our own estimates of reproductive parameters for this population. As with the 2006 data (Englund *et al*., 2007) and following Thompson *et al*. (2000), estimates of vital rates were obtained from the published literature and these data were used as input parameters (Table 2). We considered VORTEX to be an appropriate simulation model because it is a population model that includes both demographic and environmental stochasiticity, and allows incorporation of the effects of catastrophes, such as harmful algal blooms, on reproduction and survival. In these simulations, we assumed that the age structure was stable. Environmental variation (EV) is modelled using standard deviation.

Table 2. Parameters used in Vortex simulations including published sources.

Parameter	***Parameter value***	***Source***
First age at reproduction		
Male	11	1
Female	10	1
Maximum age	50	2
Sex ratio at birth	0.5	
Polygynous mating	75% of males in breeding pool	
Reproduction	14.4% (EV 2.44) of females produce one young not density-dependent	3
	Inbreeding depression incorporated (lethal equivalents 3.13)	4
	EV (reproduction) not correlated with EV survival	
Mortality (%)		
Age 0 – 1 years	20 (EV = 7.0)	3
Age 1 – 50 years	2.85 (EV = 0.5)	3
Frequency of type 1 catastrophe	1%	5
With 50% reduction in population		
With 25% reduction in population		
Initial pop sizes	114 and 85	
Carrying capacity	280 (EV 10)	6

1 Sergeant *et al*., 1973, 2 Read *et al*., 1993, 3 Wells and Scott, 1990, 4 Ralls *et al*., 1988, 5 Thompson *et al*., 2000, 6 Englund *et al*, 2007.

The values used for age at sexual maturity (from Sergeant *et al*., 1973) are close to unpublished values calculated for this species during the EU – funded BIOCET project (Rogan, unpublished data) and are considered reasonably robust for European animals. Similarly, the value for longevity, while taken from Read *et al*., 1993 is also similar to the oldest aged animal from the BIOCET project of 45 years. However, recently an individual aged 58yrs was recorded in the Sarasota group (Wells *et al*, 2008) and therefore it is possible that the maximum age used is negatively biased. As in the previous study

(Englund et al., 2007), we set carrying capacity as twice the largest population estimate (280).

Using lasermetrics to estimate morphometric data

Two lasers projectors were mounted onto the camera lens and used during photo-identification of dolphins (Figure 3). The lasers were set up so that parallel dots were projected onto the dolphins skin at a known distance apart (10cm). Calibration assured the lasers were parallel for at least 20 meters, a distance within which photographs of dolphins were more likely to result in high quality photographs for reliable measurements to be performed.

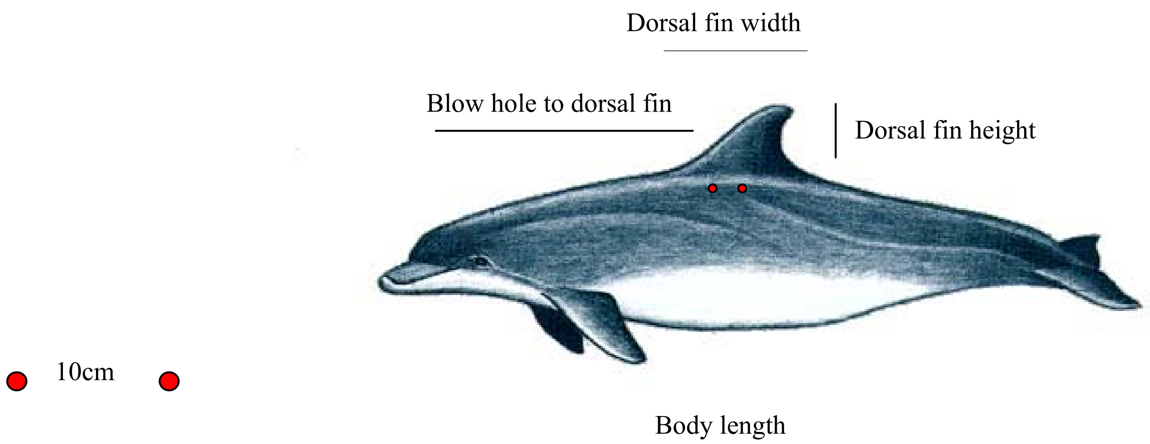


Figure 3. Showing the theoretical set up of using lasers to estimate body length of dolphins photographed. A known distance between laser spots (possible by ensuring that lasers are absolute parallel) enables calculations of lengths of body sections whose proportion to the total body length is known, e.g. dorsal fin height or width or blowhole to dorsal fin lengths in relation to total body length (calculated from stranded specimen).

Morphometric data from stranded animals (i.e. dorsal fin height or dorsal fin width) were used to derive equations to enable us to estimate total body length. In stranded animals, up to 24 external body measurements (see Figure 4) are routinely taken (to the nearest 0.5cm), including total body length (TBL), height of dorsal fin (HD) and width of dorsal fin (LD).

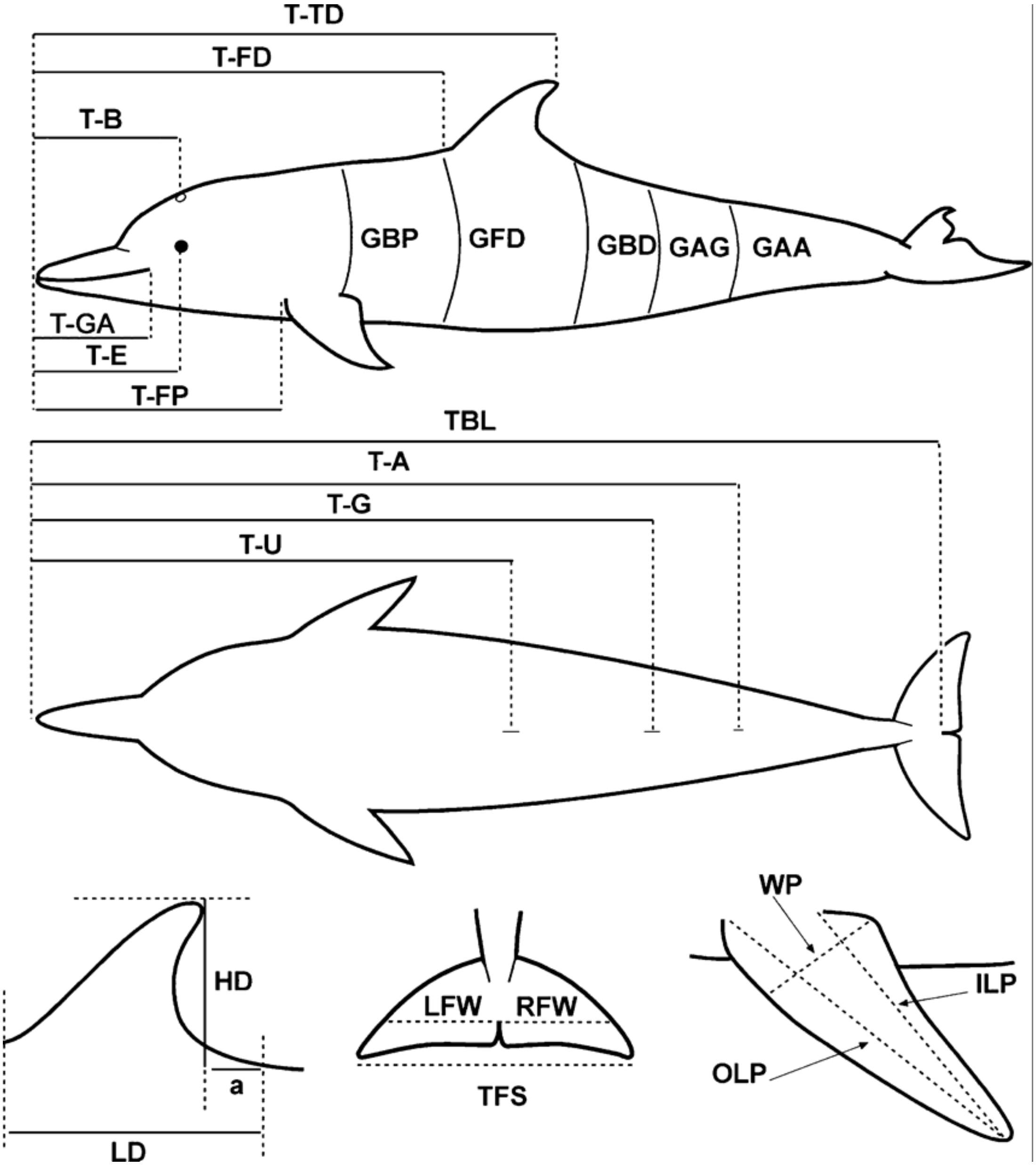


Figure 4. Drawing of external morphometric characters measured in stranded animals (from Murphy and Rogan, 2006).

In order to examine the usefulness of the measures of dorsal fin height and width, allometric growth equations were created in the form:

$Y = aX^b$

where Y = character (dependent variable),
X = total body length
a = intercept
b = growth coefficient

RESULTS

Survey effort

Eight full surveys with dolphin encounters were completed between June and September 2008. An additional survey was completed in September during which no dolphins were encountered and an additional two surveys were abandoned part way through due to deteriorating weather or sea conditions (Table 3). A total of 74.2 hours were spent on the water.

In order to broaden the survey coverage the route was extended further out to Loop Head on four occasions in 2008 (Figure 5) and also into Tralee Bay on two occasions (due to reports on large groups of animals reported in this area and very few animals sighted in the Estuary).

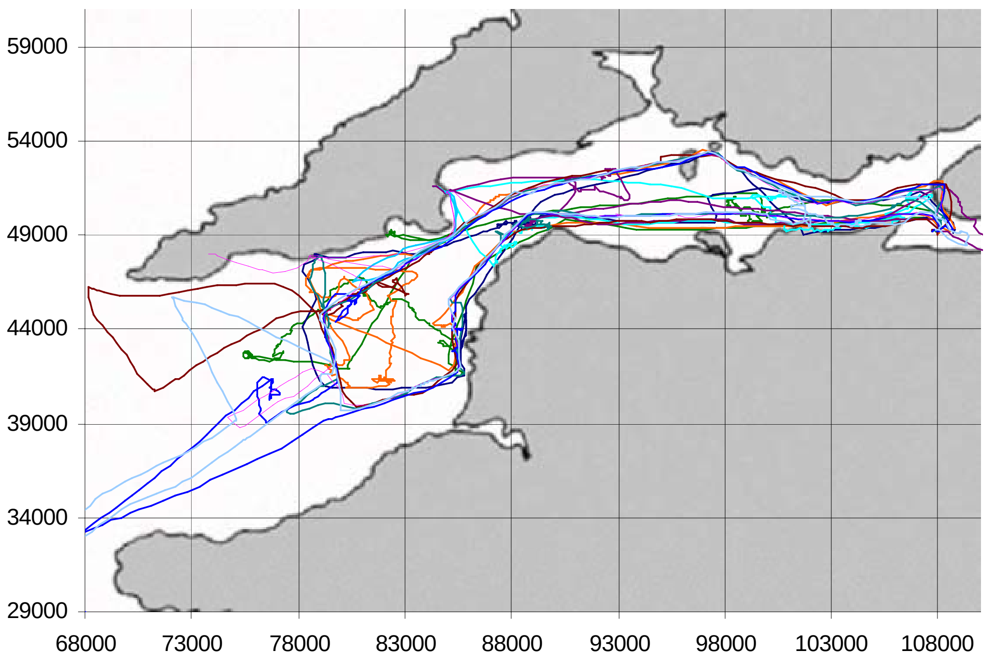


Figure 5. Map showing all survey tracks completed during the survey period. The axes show metric OSI easting and northing.

Dolphin encounters

A total of 22 bottlenose dolphin encounters were recorded on 9 survey days (Table 3). School size ranged from 2 to 36 individuals with a median school size of 6.5. Two encounters included more than 20 individuals and there were no encounters this year with lone animals.

Table 3. Survey date, number of schools encountered and number of dolphins in those schools (part surveys: August 31st and September 20th and full survey: September 23rd which yielded no photographs are indicated with an asterisk).

Date of survey	Number of schools encountered	Number of identified dolphins
June 14th	3	20
August 4th	3	32
August 8th	2	49
August 30th	2	28
August 31st *	3	15
September 7th	1	14
September 13th	2	6
September 17th	4	35
September 20th *	1	0
September 23rd *	0	0
September 28th	1	16
Total	**22**	**215**

Results of photo-identification analysis

A total of 1992 photographs taken yielded 215 identifications of 80 uniquely marked dolphins. 68 of these dolphins (86% of the total) were matched with the existing catalogue and 12 new individuals were added. Out of the dolphins matched with or added to the catalogue, 28 had permanent marks, 32 had temporary marks and 20 had superficial marks. Out of the 80 dolphins identified a total of 52 dolphins were identifiable from both sides of their dorsal fin, 43 were identified from their left and 29 from their right side (Table 4). The average number of dolphin identifications per survey was found to be lower in 2008 when compared to previous years (20.4 in 2003, 14.8 in 2006 and 11.8 in 2008).

Table 4. Number of dolphins identified from their left side, right side and from both sides. These identifications were made from high quality photographs. The degree of mark severity of identified dolphins is also shown.

	Mark severity			
Side	**Permanent marks**	**Temporary marks**	**Superficial marks**	**Totals**
Both	31	26	21	78
Left	16	25	13	54
Right	12	11	7	30

Level of disturbance

No evidence of evasive behaviour was noted during the surveys in 2008. If weak avoidance behaviours were noted the survey team moved away from the encountered group for 5 minutes and did not observe any continuation of such behaviours when the encounter was resumed. Total encounter time ranged between 1 and 206 minutes with a median of 36.5 minutes.

Sightings of juveniles, calves and neonates

Sightings of juveniles, calves and neonates were noted during surveys. Juveniles were defined as subadults <2/3 the size of adults, calves (<1 year) and neonates (<1 month old) were recognised due to their smaller size, the presence of foetal folds or lines and their close association with a larger animal assumed to be the mother. A total of ten calves were observed during 2008, five of these were likely neonates. Six presumed mothers of these calves were matched with the catalogue but four had only superficial (grade 3) dorsal fin marks and were not previously recognised (Table 5). Only one calf (#612) was sufficiently marked for repeated identification due to scarring on its flank and it was therefore incorporated in the catalogue. The calving history of seven known females that were observed with a neonatal calf during either of the survey periods in 2003, 2006 or 2008 is presented in table 6. Due to absence of data from other years it is possible that females gave birth more frequently than is reported here.

Table 5. Calves and neonates (age likely below 1 month) when first encountered during 2008 including their escorting adult (assumed to be the mother) and the mark degree of this escort.

Date of first sighting	Calf or neonate	Escorting adult number	Degree of marking of escort
04-Aug-08	calf	422	2
08-Aug-08	neonate	Unmarked	3
30-Aug-08	neonate	101	2
31-Aug-08	neonate	Unmarked	3
31-Aug-08	neonate	Unmarked	3
17-Sep-08	calf	Unmarked	3
17-Sep-08	neonate	586	3
17-Sep-08	calf	462	2
28-Sep-08	calf	543	2
28-Sep-08	calf	553	1

Table 6. The calving history of five well marked mothers observed with a neonate or calf during the three survey periods used for estimates of abundance (2003, 2006 and 2008) is shown below.

Female	2003	2004	2005	2006	2007	2008
19	no calf seen	?	?	neonate	?	not seen
74	neonate	?	?	no calf seen	?	no calf seen
101	neonate	?	?	calf/juv	?	neonate
145	no calf seen	?	?	neonate	?	no calf seen
286	neonate	?	?	neonate	?	juvenile
422	not seen	?	?	no calf seen	?	calf
425	neonate	?	?	no calf seen	?	no calf seen

Sightings of permanently marked dolphins

There were a total of 28 permanently (grade 1) marked dolphins identified during the survey period. Of these, 32 were identified from their left side, 20 from their right side and 18 from both sides. Two of these individuals were not previously catalogued (#s 616, and 618).

Examination of year of first identification for all marked animals (grade 1 and 2) showed that even though some well known individuals were not encountered this year, most of the animals encountered were known from several years previously. Out of the marked individuals encountered in 2008, 92% were seen in 2006 and 70% also in 2003. In fact, 19 dolphins were known from as far back as 1997.

The total number of permanently marked dolphins sighted in 2008 (and known from at least 2003) compared with the numbers sighted in 2003 and in 2006 showed a markedly lower sightings rate. Additionally, some very well known individuals (n=11) were not sighted at all this survey period (Table 7). Only sightings with good quality photographs obtained for at least one side were used for these comparisons.

Table 7. Number of sightings of permanently marked (grade 1) individuals encountered during 2003, 2006 and 2008. Sighting rates are corrected for number of surveys to account for differences in survey effort between survey years. Only animals known from 2003 are included.

Catalogue number	2003	Rate -03	2006	Rate-06	2008	Rate-08
1	3	0.21	3	0.25	0	0
18	6	0.43	2	0.17	0	0
19	3	0.21	3	0.25	0	0
24	2	0.14	3	0.25	4	0.50
29	3	0.21	4	0.33	0	0
33	3	0.21	0	0	0	0
34	2	0.14	1	0.08	0	0
36	0	0	4	0.33	0	0
56	3	0.21	3	0.25	2	0.25
57	2	0.14	0	0	0	0
60	2	0.14	0	0	0	0
72	5	0.36	3	0.25	0	0
73	1	0.07	2	0.17	1	0.13
100	2	0.14	0	0.00	0	0
109	2	0.14	1	0.08	0	0
136	3	0.21	3	0.25	4	0.50
139	2	0.14	5	0.42	1	0.13
145	1	0.07	0	0	1	0.13
155	1	0.07	1	0.08	1	0.13
180	2	0.14	3	0.25	1	0.13
222	4	0.29	1	0.08	0	0
244	5	0.36	3	0.25	1	0.13
282	7	0.50	2	0.17	1	0.13
292	3	0.21	6	0.50	1	0.13
299	1	0.07	0	0	0	0
302	2	0.14	2	0.17	3	0.38
334	1	0.07	1	0.08	2	0.25
368	3	0.21	5	0.42	1	0.13
382	4	0.29	1	0.08	1	0.13
384	1	0.07	2	0.17	3	0.38
398	3	0.21	1	0.08	2	0.25
402	5	0.36	2	0.17	0	0
412	2	0.14	1	0.08	1	0.13
419	3	0.21	1	0.08	2	0.25
432	1	0.07	0	0	0	0
434	4	0.29	0	0	0	0
445	2	0.14	5	0.42	1	0.13
453	3	0.21	1	0.08	0	0.00

Ranging patterns of permanently and temporarily marked dolphins

Dolphin ranging patterns during 2008 were similar to previous years as were differences in use of the SAC by individuals. Of all permanently or temporarily marked animals (n=80), 78% were only recorded in the outer parts of the Estuary, west of the Beal Bar (N52º 35.5’, W9º 38.4’), 6% were sighted only in the up-river part of the Estuary (east of the Beal Bar (N52º 35.5’, W9º 38.4’) and 16% of all individuals were observed using the entire study area. The compact disk accompanying this report includes maps of distribution of all marked individuals within the Shannon SAC in 2008.

Mark-recapture estimate

The rate at which well-marked individuals were recruited into the marked subset (‘discovered’) steadily decreased throughout the study and is shown in a discovery curve below (Figure 6). No new individuals were recorded in the last survey included in abundance estimate calculations (survey 164). This indicates that the population was likely closed during the mark-recapture sampling period. The dataset used in capture-recapture analysis included 95 sightings of 53 marked individuals with a mean individual sightings rate of 1.79.

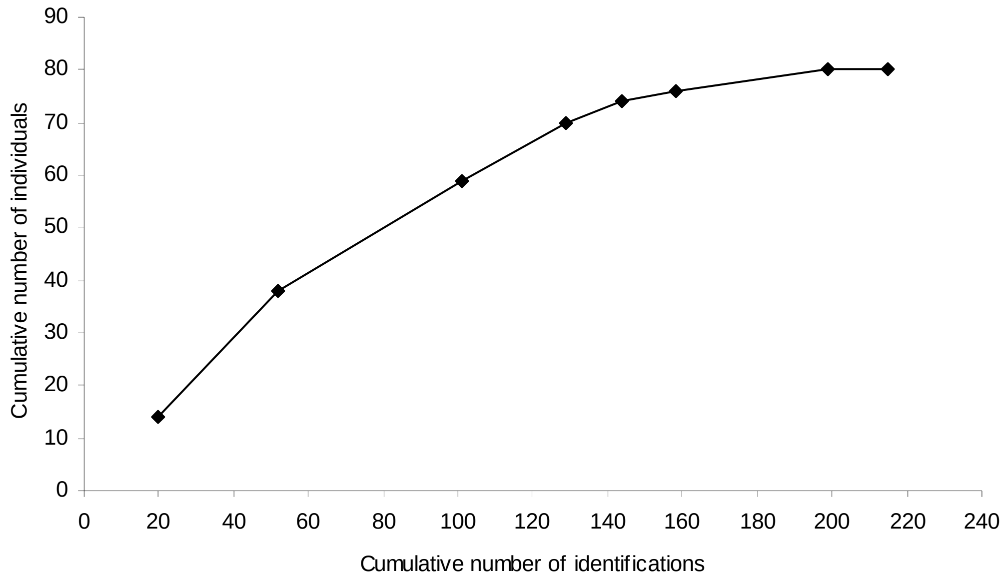


Figure 6. Discovery curve showing the cumulative number of individuals identified with increased survey effort during 2008.

Estimates of number of marked dolphins using the Shannon

Photo identification data from eight surveys were used in a mark-recapture procedure. High quality images were selected of well-marked individuals (approximately 80% of the dolphins encountered) and used to construct a sightings matrix. This matrix was used to estimate the abundance of marked dolphins using the Shannon using model M_{th} (Chao *et al.,* 1992) within the dedicated software programme CAPTURE (Table 8). Model M_{th} was chosen due to its tolerance of sources of heterogeneity in capture probabilities between individual animals and between surveys. The resulting estimate was inflated according to the proportion of all identifications represented by marked dolphins to give an estimate of the total abundance of dolphins using the Shannon (Table 9)

Table 8. Estimate of abundance of dolphins using the Shannon SAC during June to September 2008 where n=number of identified marked dolphins, s = number of sightings of marked dolphins, Nhat=estimated total number of marked dolphins, θ = proportion of marked dolphins in the sampled population, N = estimated total abundance, se = standard error of the estimate, CV = coefficient of variation of the final estimate.

n	s	Nhat	θ	N	Se	CV	95% CI
53	95	72	0.63	114	16.9	0.15	85-152

Table 9. The proportion of marked dolphins (grade 1 and 2 markings) in the Shannon population (theta). Theta (θ) is the proportion of identifications of marked dolphins made from quality grade 1 photographs.

Total number of ids	Number of ids of marked animals	Proportion of animals with marks, theta (θ)
196	124	0.63

Population Viability Analysis (PVA)

With the current estimate of population size (114 dolphins) and using published reproductive parameters from other studies, the simulation predicted that in the absence of catastrophes, the population would grow to a mean size of 160 ± 2.18 (SE) after 250 years. Using a similar simulation but with the single catastrophe scenario, the probability of extinction is 0.036 with a mean (remaining) population of 81 ± 1.98 (SE) after 250 years.

We then ran VORTEX using a starting population size of 85 dolphins, the lower bound of the CI. Starting with the lower population size of 85 individuals and with no catastrophes, the probability of extinction is 0.031, although with a positive growth rate increasing the mean population size to 109 ± 2.11(SE) after 250 years. As expected, with one catastrophe, the probability of extinction increases to 0.18 and the mean population size after 250 years is predicted to be 52 ± 1.45 (SE).

Results of lasermetrics testing

Trials using lasers mounted on the lens of the camera during photo-identification proved successful (Figure 7) and resulted in a number of useful photographs for estimating body length of dolphins encountered in the wild.

Lasers were visible on approximately 24 photographs taken in 2008. Nine of these were of sufficient quality for use in morphometric calculations (Figure 7). The others were excluded from the analysis on the basis of distance or the angle of the animal in the photograph, which would have resulted in unreliable measurements. The successful photographs were taken on three of the surveys and ten images with well projected and clear lasers were taken of six different individuals of which five were previously known (#136, 460, 558 and 619) and one new to the catalogue for this year (#619). One is a known male (#136) and some of the others have been biopsied and await results of gender determination.

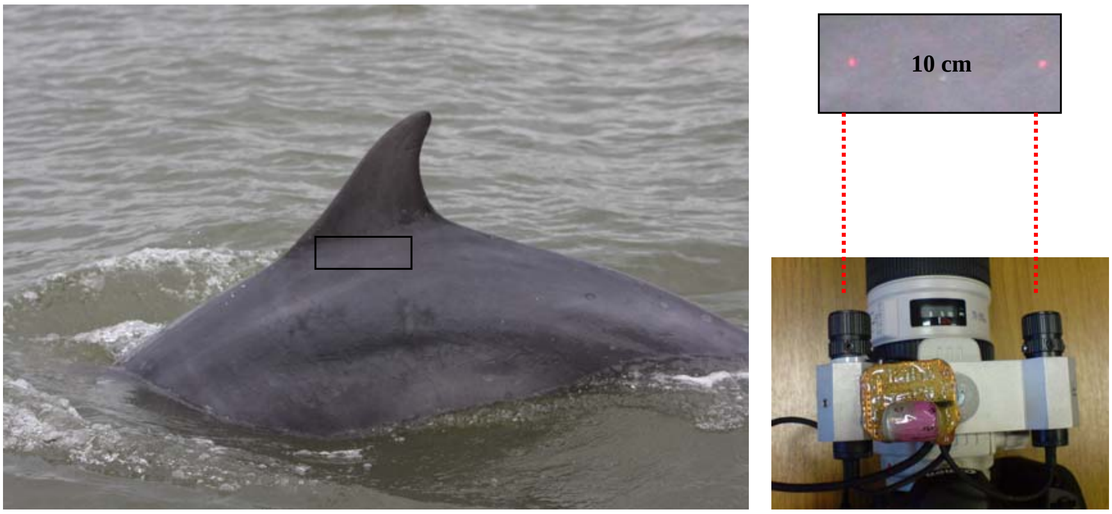


Figure 7. Showing one of the individuals (#619) successfully photographed with the lasers projected. The set up of the laser projectors on the camera lens is shown on the right.

Most of the photos with laser marks were photos where only the dorsal fin was present (as opposed to other features, such as the blowhole or eye). However, it was possible to extrapolate the laser measurements to obtain measures of fin height and fin width for these animals. The results are summarised in the Table below (Table 10).

Table 10. The photoframes, ID number and height and width of dorsal fins from some Shannon dolphins.

Photo-frame	ID number	Dorsal fin width (cm)	Dorsal fin height (cm)
08-157-0057	619	36.6	26.2
08-157-0058	619	36.7	26.0
08-157-0072	460	46.4	30.0
08-157-0074	460	46.4	29.5
08-157-0090	619	46.8	25.2
08-157-0093	460	44.1	29.3
08-157-0175	621	46.4	25.0
08-160-0010	136	50.8	32.4
08-157-0202	558	48.7	30.3
08-161-0107	588	48.6	22.3

Of all stranded bottlenose dolphins recovered for post-mortem examination since 1996, full morphometric measurements were available from 14 animals, 6 males and 8 females. Given the small sample size, sexual dimorphism was not tested and data for both genders were pooled. Total body length in the stranded animals ranged from 287 – 340cm, with fin width ranging from 35 – 61cm and fin height from 24 to 37cm. The dorsal fin measurements compare well to what was calculated from the photographed animals.

Allometric measurements for the two dorsal fin measurements were regressed against total body length for males and females combined. The derived equations are as follows:

$$Y = 110.72\ X^{0.2675} \quad \text{where } X = \text{Dorsal width}$$

$$Y = 165.55\ X^{0.1829} \quad \text{where } X = \text{Dorsal height}$$

In both cases, negative allometric growth is seen to occur (b is significantly < 1). As a result of the paucity of data (and likely sexual dimorphism), the R^2 values for both dorsal fin measurements were poor, although the width of the dorsal fin provided a better fit than fin height. The equation tested against the original dataset suggests that using dorsal fin width as a predictor will underestimate total body length. Using dorsal fin width, total body length was extrapolated, but these results should be treated with caution. The extrapolated lengths ranged from 282.7 – 315.8cm. Despite the lack of a strong relationship between dorsal fin measurements and total body length, it may be possible to use the known fin size to estimate distance from other "linear" characters, such as the distance from the blowhole to the start of the dorsal fin, which would probably be a more useful measure to extrapolate to total body length.

DISCUSSION

As in previous years, photo-identification boat surveys of dolphins in the Shannon SAC followed a standard survey route. This route has been used since the start of dedicated surveys in 1996 (Ingram, 2000) and covers the areas of the estuary most intensively used by bottlenose dolphins (Ingram & Rogan, 2002). Dolphins were encountered throughout the survey area in 2008 and schools were encountered and photographed in 9 of the 11 surveys. The survey team took great care to minimise any disturbance effects during data collection and no excessive reactions to the survey boat were observed during the course of the study. The surveys resulted in 22 encounters with dolphin schools, 1,992 photographs and 215 identifications of 80 naturally marked individuals. The photographs were carefully matched within and between encounters and surveys to minimise any mistakes in identification. It is important that this is done thoroughly since any estimates of population size or changes in distribution depend on the quality of the photographic analysis.

Long term residency and site fidelity

Data collected during 2008 confirm previous findings showing a high degree of site fidelity of dolphins using the Estuary (Ingram & Rogan, 2001; Englund *et al*., 2007) with the majority of marked dolphins known since the start of survey effort in the late 1990s. The degree of marking effects the probability of re-identification and the majority of dolphins only seen once or twice during this study consisted mainly of poorly marked animals.

Approximately one-third of permanently marked individuals sighted in 2006 were not sighted in 2008. It is unclear whether this indicates a genuine absence of members of the community from the SAC or a sampling effect resulting from lower sampling effort. However, as seen in Table 7, the sighting rate for those animals seen in all three years, while variable, is similar, suggesting that these animals were absent during the 2008 sampling season.

A similar pattern of habitat partitioning to previous years was evident in 2008. The majority of dolphins encountered were using the outer SAC including the critical area described at the Estuary mouth (figure 1), while some were only seen inside the Estuary east of the Beal Bar (N52º 35.5’, W9º 38.4’). A total of 13 individuals were using both core areas and 6 were only observed in the inner parts resulting in 23% showing at least some use of the inner critical area and 94% showing at least some use of the outer.

Calves and neonates

Ten calves/neonates were recorded during this survey, all of which were first sighted between August and September 2008. Due to low degrees of marking for calves they can generally only be reliably identified from their mother making estimation of survival rates very difficult, especially with poorly marked breeding females (5 out of 10 in 2008). As with previous years, calving appears to be concentrated during the late summer-autumn period.

Calving frequency of females in the Shannon appears similar to that found in studies of other populations. It is believed that the calving interval for bottlenose dolphins may be between 3 and 4 years but with differences depending on age of the female. For example, Wells (2000) showed that the calving interval for wild populations depend on the age class and ranges between 3 to 6 years with younger females producing calves more frequently. This age related change in fecundity has also been described for captive populations (Duffield *et al.*, 2000). Continued research using lasermetrics as tested during this study may help resolve whether this is true for the Shannon population as well.

Abundance of dolphins using the Shannon

Individual recognition of dolphins from photographs of their natural markings provides a powerful tool in estimating abundance using traditional mark-recapture models. We reduced potential matching errors by screening the data of poor quality photographs and poorly marked animals. Surveys conducted during June to September 2008 provided data for a mark-recapture abundance estimate using model Mth (Chao, 1992) within the dedicated software programme CAPTURE (Rexsted & Burnham, 1991). The discovery curve shown in Figure 6 shows a steady decline in the rate at which marked animals were recruited into the sampled population and there was no indication of a significant migration of dolphins into or out of the SAC during the sampling period. We can be confident therefore that the majority of marked animals had been sighted during these surveys and thereby considered the population to be closed during the sampling period. In previous estimates we derived separate estimates from left side and right side identifications, inflated these according to the proportion of marked animals and then combined them to give a final estimate. This year, due to a reduction in the survey effort, we pooled all left and right side identifications from all animals known from both their left and right to increase estimate precision. Whilst this reduced the number of animals in the sampled population (since a proportion of dolphins are only known from one side) it served to increase the average number of sightings of each individual (from approximately 1.3 to 1.7) and increased the total number of sightings included in the capture matrix. We estimated the total number of dolphins using the estuary between June and September 2008 to be 114 ±17 (CV=0.15, 95% CI 85-152). This compares with previous estimates of 140 ±12 (SE) (CV=0.08, 95% CI 125-174) from 2006, 121 ±14 (SE) (CV=0.12, 95% CI 103-163) from 2003 and 113 ± 14, CV=0.14, 95% CI 94-161) from 1997. The latest estimate has a lower precision (higher CV value) than all previous estimates and whilst it appears to indicate a lower number of dolphins were using the SAC during 2008, the 95% confidence interval spans all previous estimate values preventing us from identifying a significant reduction in abundance.

However, the low estimate, together with findings of lower sighting rates, surveys with few or no sightings and the absence of some well known individuals, all point towards the possibility that fewer animals were actually present in the Shannon during the survey period of 2008. The lower level of survey effort, in combination with less than ideal weather conditions, may partly explain these findings. It is also possible that unusually windy weather during the summer of 2008 may have affected the distribution of dolphins (or their prey species) in ways that we do not fully understand.

Optimising monitoring strategy

In 2006 we used a permutation procedure to run CAPTURE with data from increasing numbers of surveys in order to model the effect of increased survey effort on estimate precision and other capture-recapture parameters such as mean individual capture frequency (Englund *et al.*, 2007). We also examined the effect of different levels of estimate CV on the ability of monitoring surveys to detect population decline using a variety of reporting strategies.

As a result of this work we recommended that estimate precision (low CV values) should be a priority when designing future reporting strategies. In light of the importance of maintaining low estimate CV values we recommended that regardless of reporting frequency, monitoring for this population should include at least 12 surveys within each sampling period in order to derive a robust and precise estimate. Our calculations indicated that 12 surveys should be sufficient to derive an estimate with a CV below a threshold value of 0.12 and would likely include approximately 2 sightings of each identified dolphin. This level of sampling effort is realistic within a typical summer and will maximise the likelihood of recording most of the marked dolphins using the SAC during the survey period. The aim was to estimate the optimal number of surveys required to obtain a robust estimate with an acceptable CV.

Regarding trend detection sensitivity, precise estimates with low CV values (<0.1) were demonstrated to greatly reduce the time predicted to detect population trends. Although the detection time (of a hypothetical 5% annual decrease) was shown to increase with a reduction in reporting frequency, by maintaining high levels of precision (CV <0.10) this detection delay could be offset. Generally, annual surveys proved to be the best option for many reasons including higher trend detection sensitivity and efficient recording of calf production and individual changes in identifying markings (reducing the chance of losing animals from the catalogue). Unfortunately, an annual reporting strategy with low survey effort will produce imprecise estimates with less sensitivity to population decline detection. In addition, lower survey effort will provide less information on individuals using the SAC or movements of animals into and out of the Estuary.

In order to achieve an estimate with as low a CV as possible, the sightings data for left and right identifications in 2008 were pooled. This was a different approach than we have used in previous years but deemed sensible due to the lower survey effort during 2008. Only animals known from both sides were included in the mark-recapture analysis in order to exclude the artificial inflation of the resulting estimate by including animals only known from one side. Whilst this procedure reduced the number of animals available for inclusion in the mark-recapture sample set, the number of sightings per individual was increased. Through this pooling of left and right identifications the mean individual capture rate of animals included in the marked subset during 2008 was 1.7 sightings per dolphin. The figure for separate left and right sightings independently was only 1.5, a figure we considered to be critically low and presenting a risk of producing an unreliable estimate. Previously we have recommended it advisable to aim for at least 2 sightings per individual in order to achieve a precise estimate (low CV). In 2006, our survey effort achieved 2.5 sightings per dolphin from 16 surveys resulting in an estimate with a CV of 0.08. It is clear that the sighting frequency of individuals will directly affect estimate precision and in theory it may be possible to examine the sightings rate during a sampling season to get an indication of progress when aiming for a target estimate CV.

The effect of estimate precision on trend detection times in different reporting frequencies is shown in figure 8. With the current estimate precision (CV = 0.15) a population decline of 5% will be expected to be detected within a period of twelve years. The same sensitivity could be achieved with a biennial reporting strategy providing estimate precision is maintained below 0.12 (CV). The benefits of more intense survey effort also include greater detail in the movements, association patterns and mark changes of individuals. Whilst there is clearly a trade off between monitoring costs and estimate precision and monitoring sensitivity, the higher survey effort we recommend is likely to represent only a marginal increase in overall monitoring costs within a given reporting cycle. Ideally we recommend annual monitoring surveys should be conducted with this level of effort but in the case of limited resources a less frequent reporting cycle is preferable to a decrease in survey effort during any single reporting year.

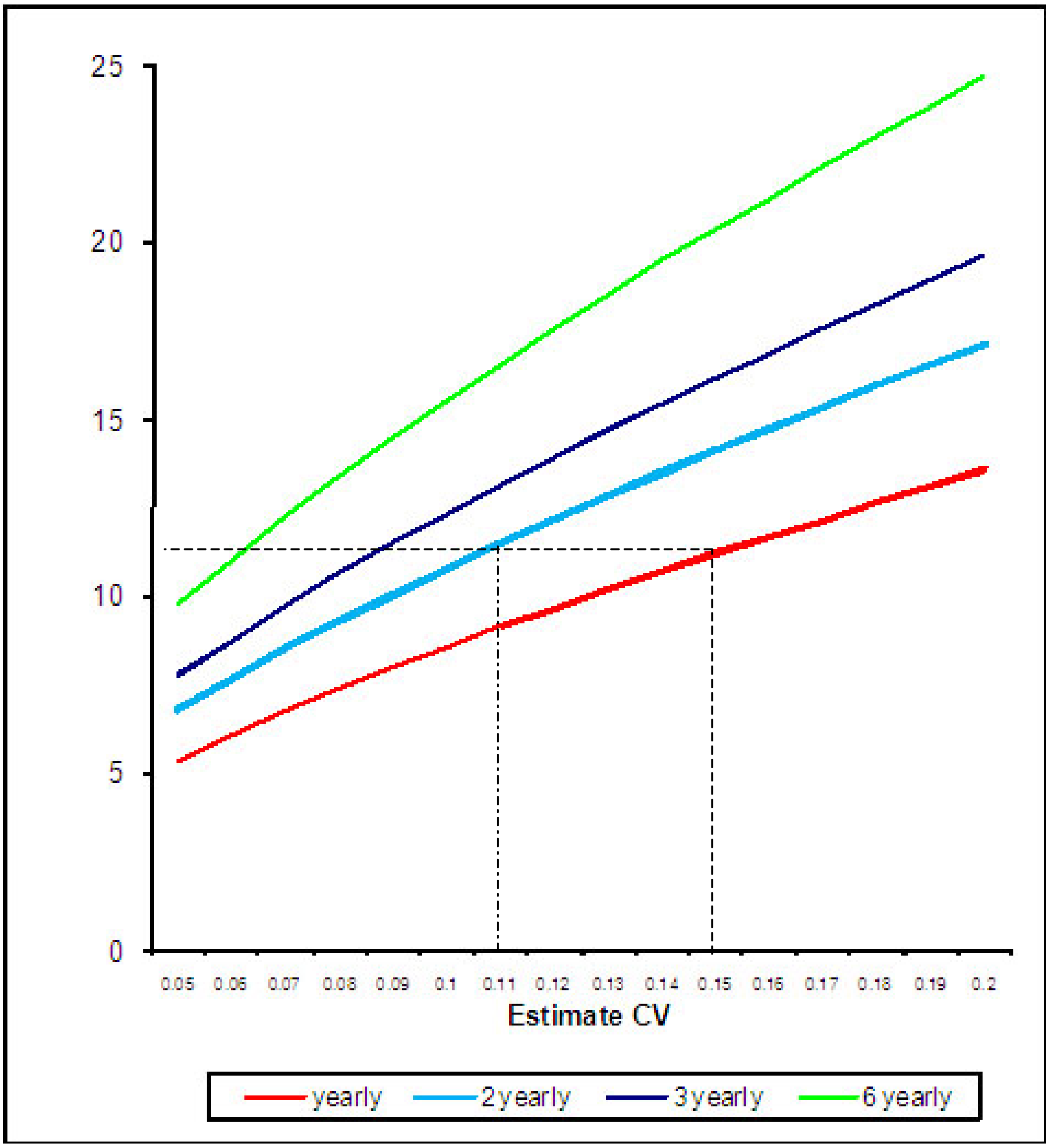


Figure 8. The predicted time to detect an annual rate of change of 5% in the Shannon dolphin population using different monitoring periods. The dashed lines show the time to detection with the current estimate precision of CV=0.15 within the four monitoring strategies. With an annual reporting framework a rate of population change of 5% per annum will be detected within 12 years (years to detection is shown on the y-axis. The same detection time can be achieved with a biennial reporting strategy (dash-dot line) with more precise estimates (CV ≈ 0.11).

Population viability analysis

Inherently, small populations are more vulnerable to extinction and in order to model the stability of the Shannon dolphin population we used four different scenarios within the programme Vortex to simulate population viability over a 250year period. As expected, simulations showed that in the absence of a "catastrophe" and carrying capacity set at 280 individuals, that over the 250 year simulated period that both populations with starting populations of 114 individuals and 85 individuals would increase. However, introducing one catastrophe (at a frequency rate of 1%, with a 50% reduction in reproduction and a 25% reduction in survival) caused both "simulated populations" to decline. This is consistent with results from Thompson *et al*. (2000) who found that with populations below 100 that the long-term probability of extinction is relatively high.

As stated previously, although the frequency of catastrophe rate (1%) with a 50% reduction in reproduction and a 25% reduction in survival are set quite high, they are not unrealistic, especially if taken in the context of disease outbreaks. Dolphin morbillivirus (DMV), for example, was responsible for the deaths of thousands of striped dolphins (*Stenella coeruleoabla*) in the Mediterranean (e.g. Domingo *et al*., 1990), and resulted in several epizootics in bottlenose dolphins in the NW Atlantic (e.g. Duignan *et al*., 1996), while domoic acid or brevetoxin poisoning associated with harmful algal blooms (see Fire *et al.,* 2008) has also resulted in the deaths of bottlenose dolphins and humpback whales (*Megaptera novaeangliae*) in Florida. It must also be noted that our simulations used reproductive parameters measured in other populations and must be viewed at best as approximations when applied to dolphins living in Irish waters. Without increased survey effort and annual information on calving, survival and mortality rates accurate PVA models using measured parameters will not be possible.

Lasermetrics

The lasers were reasonably easy to use alongside the routine photo-identification work. In relation to analysis of fin height, on one occasion, photos analysed were of the same animal and on another occasion, the same animal was analysed three times. The photos were analysed separately and while the method appears to be reasonably consistent, with very little difference in fin height or width between two sets of photos, and certainly within the same degree of accuracy as measurements taken during post-mortem examination, on another occasion (# 460), the dorsal fin width was 2cm smaller, highlighting the importance of establishing more criteria in relation to angle and position of the fin to allow for more rigorous comparisons. We believe that a number of elements could improve our future use and make the results more accurate, including re-calibrating the lasers after the end of each survey and making sure fin shots are parallel in the photographs (as opposed to at an angle). With a larger data set of animals, and extrapolating the dorsal fin size to a longer measurement, such as distance between blow hole and start of dorsal fin, it is hoped that this technique can be applied with greater certainty in future studies.

Dolphins at other west coast sites

Additional work on bottlenose dolphins outside of the Shannon should be continued in order to provide contextual information regarding the reproductive isolation or meta-population structure of dolphins on the west coast. It is still unclear how far Shannon dolphins range outside of the SAC and the extent to which they are exposed to environmental risks in offshore areas or in other coastal locations. Additionally, present protection offered by the SAC may not extend to other coastally resident bottlenose dolphins, which may reside entirely within Irish waters but seldom or never enter the Shannon Estuary. The importance of the Shannon SAC at a larger coastal scale should be considered if, for example, changes in dolphins ranging patterns reduce the use of the SAC in future years (see Wilson *et al.,* 2004). The larger coastal population may consist of a network of interbreeding sub-populations whose long-term status depends on the movement of individuals and genetic transfer between sites. Changes in ranging patterns, local declines or extinctions of related communities are likely to have a detrimental affect on the status of the population at large.

Potential threats to the Shannon dolphins and recommendations for future monitoring.
Currently, the dolphins using the Shannon Estuary appear to belong to a small discrete population. The Shannon is clearly a site of both national and international importance to the species and should be regarded as a marine conservation priority. In view of the time needed to detect population change and the population decline inevitable before detection and mitigation measures are established, it is important to maintain frequent monitoring of this population. Every effort should be made to maintain frequent reporting and precise estimates to minimise any potential population decline before detection. A precautionary approach is preferable without relying on statistical detection of population decline before protective measures are implemented. Bottlenose dolphins using the Shannon are potentially at risk from habitat degradation and direct and indirect disturbance from human activities. The Shannon is a busy waterway and the region is a major centre of industry. The mouth of the Estuary is the most intensively used part of the SAC visited year-round by the majority of dolphins using the Estuary. Any industrial development such as, wind-turbine construction, destructive fishing activity, dredging, or blasting should, if possible, be prevented in this area.

Summary of recommendations for future monitoring schemes
As previously stated here and in previous reports we recommend the following:
1. Maintenance of a higher level of monitoring survey effort in future years.
2. Extension of survey effort to waters outside the Shannon SAC.
3. Water quality monitoring for the presence of contaminants
4. Fish stock surveys in order to monitor the status of dolphin prey resources;
5. Necropsy analysis of stranded animals to determine diet, cause of death and contaminant burden and to provide samples for genetic analyses;
6. Monitoring the growth and activity of the dolphin watching industry;
7. Monitoring of fishing effort and by-catch within the Estuary.

1. As discussed in detail in this and previous reports (Ingram *et al*., 2003; Englund *et al.* 2007) we highlight the importance of estimate precision in an effective monitoring strategy. We recommend greater survey effort should be commissioned in future years with at least 12 surveys conducted within summer sampling periods. In order to detect animals using the estuary during different months this effort should be spread throughout the summer with two surveys per month between June and September and an additional four surveys conducted during fine weather periods during this time. Provision should be made for a few extra surveys to compensate for surveys abandoned due to deteriorating weather. Work from previous years has shown the effectiveness of such a strategy and our data modelling shows that such a strategy should be sufficient to yield robust precise and reliable estimates.

2. Whilst the Shannon appears to be the most important coastal area for bottlenose dolphins in Irish waters results of other surveys has shown a relatively high abundance of bottlenose dolphins around other coastal areas (Ingram *et al.*, 2001; Ingram *et al*., 2003, Ingram and Rogan, 2003). Preliminary work has shown these dolphins appear to belong to a separate community or sub-population to the dolphins using the Shannon and current genetic analysis indicates a degree of reproductive segregation (Miller, unpublished data). In order to effectively manage bottlenose dolphins in Irish waters survey effort should be directed at examining dolphins using these coastal waters outside the Shannon. The population structuring of bottlenose dolphins using Irish coastal waters needs to be better understood in order to plan an effective management framework.

3. Efforts should be made to identify and quantify the present threats to dolphins using the Shannon SAC including an examination of contaminant levels in the Estuary. Although the dolphins using the Shannon have recently been shown to have low concentrations of measured contaminants (Berrow *et al.,* 2002) a regular water sampling and analysis programme would serve to identify rising contaminant levels and ensure that water quality standards are maintained.

4. Little work has been done to survey the fish species present in the Shannon Estuary (see O'Sullivan, 1984) other than salmon and eel migration studies (Moriarty, 1974; Anon, 1998). The use of the Shannon Estuary by bottlenose dolphin population is likely to depend on the availability of various prey species. A comprehensive survey of fish species present in the Estuary and regular repeated sampling would provide valuable information on the changes in abundance of prey over time and would help identify possible causes to changes in the use of the Estuary by dolphins. Stable isotope ratios of δC and δN in fish tissue could be compared with samples taken from dolphin skin biopsies and would provide valuable data for examining dolphin foraging in the SAC.

5. Necropsy studies of stranded dolphins found in the Estuary would provide important information regarding, cause of death, life history parameters (e.g. longevity, age at sexual maturity) and diet and would provide indications of the contaminant burden in dolphins using the Estuary. In addition, necropsy samples can be used to determine stock structure through genetic analysis. Such work would help to determine the reproductive isolation of this population from adjacent ones and provide data on paternity and genealogy.

6. The growth of the dolphin watching industry in the Shannon should be monitored and efforts made to ensure that disturbance to dolphins is minimised. The adherence to the existing precautionary codes of conduct should be maintained and a training programme for new operators established. In addition to physical disturbance, boat traffic can cause acoustic pollution and disrupt co-operative behaviour and communication between individuals. Important consideration should be given to the acoustic quality of the dolphins' environment in order to minimise the degradation of their habitat.

7. Fishing activity within the Estuary could affect dolphins directly through by-catch fatalities or indirectly through prey depletion. By monitoring fishing effort and by-catch incidents the level of these affects could be measured and mitigated.

REFERENCES

Acevedo, A. 1991. Interactions between boats and bottlenose dolphins, *Tursiops truncatus,* in the entrance to the Ensenada de La Paz, Mexico. *Aquatic Mammals* **17(3)**: 120-124.

Anon. 1998. Electricity Supply Board Fisheries Conservation Annual Report*, (May 1997 to April 1998)*, 70pp.

Arnold, H. 1993. Distribution, abundance, and habitat use of bottle-nosed dolphins in Cardigan Bay, Wales, 1992. *European Research on Cetaceans* **7:** 63–66.

Au, D. and Perryman, W. 1981. Movement and speed of dolphin schools responding to an approaching ship. *Fishery Bulletin* **80**: 371-379.

Baines, M.E., Reichelt. M., Evans, P.G.H., Shepherd, B. 2002. Comparison of the abundance and distribution of harbour porpoises (*Phocoena phocoena*) and bottlenose dolphins (*Tursiops truncatus*) in Cardigan Bay, UK. Pp. 12-13. In: Abstracts, 16th Annual Conference of the European Cetacean Society, 7-11 April, Liège, Belgium.

Berrow, S.D. and Holmes, B. 1999. Tour boats and dolphins: A note on quantifying the activities of whale watching boats in the Shannon Estuary, Ireland. *Journal of Cetacean Research and Management.* **1(2)**: 199-200.

Berrow, S.D., McHugh, B., Glynn D., McGovern, E., Parsons, K., Baird, R.W. and Hooker, S.K. 2002. Organochlorine concentrations in resident bottlenose dolphins *(Tursiops truncatus)* in the Shannon Estuary, Ireland. *Marine Pollution Bulletin*. **44**: 1296-1313.

Blane, J.M. and Jaakson, R. 1994. The impact of ecotourism boats on the St. Lawrence beluga whales. *Environmental Conservation* **21(3)**: 267-269.

Caswell, H., Fujiwara, M. and Brault, S. 1999. Declining survival probability threatens the North Atlantic right whales. *Proceedings of the National Acadamy of Science*, **96**: 3308-3313.

Chao, A., Lee, S.M. and Jeng, S.L. 1992. Estimating population size for capture-recapture data when capture probabilities vary by time and individual animal. *Biometrics* **48**: 201-216.

Cheney, B., Barton, T. And Thompson, P.M. 2008. Using lasermetrics to measure wild bottlenose dolphins. Poster presented at the 22nd annual conference of the European Cetacean Society, Netherlands.

Corkeron, P.J. 1995. Humpback whales (*Megaptera novaeangliae*) in Hervey Bay, Queensland: behaviour and responses to whale-watching vessels. *Canadian Journal of Zoology* **73**: 1290-1299.

Duffield, D.A., Ahell, D., and Dudley, M. 2000. Demographic analysis of breeding bottlenose dolphins in North American zoological facilities: 1976-1998, in Report from the Bottlenose Dolphin Breeding Workshop, Duffield, D.A., and Robeck, T.R. (Eds), American Zoological Association Marine Mammal Taxon Advisory Group, Silver Spring, MD, pp139-156.

Domingo, M., Ferrer, L., Pumarola, M., Marco, A., Plana, J., Kennedy, S., McAlisky, M., Rima, B.K. 1990. Mobillivirus in dolphins, *Nature,* 348, 21.

Dos Santos, M.E. and Lacerda, M. 1987. Preliminary observations of the bottlenose dolphin (*Tursiops truncatus*) in the Sado Estuary (Portugal). *Aquatic Mammals* **13(2)**: 65-80.

Duignan, P., House, C., Odell, D.K., Wells, R.S., Hansen, L.J., Walsh, M.T., St Aubin, D.J., Rima, B.K., Geraci, J.R., 1996. Morbillivirus in bottlenose dolphins: evidence for recurrent epizootics in the western Atlantic and Gulf of Mexico. Marine Mammal Science, **12**; 495 – 515.

Durban, J.W., and Parsons, K.M. 2006. Laser-metrics of free-ranging killer whales. *Marine Mammal Science*, **22 (3)**: 735-743.

Englund, A., Ingram, S. and Rogan, E. 2007. Population status report for bottlenose dolphins using the Lower River Shannon SAC, 2006 – 2007. *Final report to the National Parks and Wildlife Service*, Ireland, pp37.

Englund, A., Coleman, M. and Collins, C. 2006. Marine mammal monitoring in Broadhaven bay: June – September 2005. *Project report to RSKENSR Group Plc*. Coastal and Marine Resources Centre, University College Cork. 40pp.

Evans, P. and Hammond, P.S. 2004. Monitoring cetaceans in European waters. *Mammal review* **34(1)**: 131 – 156.

Evans, P.G.H. and Nice, H. 1997. Review of the effects of underwater sound generated by seismic surveys on cetaceans. *Sea Watch Foundation*, Oxford, U.K., 50pp.

Fire, S.E., Flewelling, L.J., Wang, Z., Naar, J., Henry, M.S., Pierce, R.H., Wells, R.S. 2008 Florida red tide and brevetoxins: Association and exposure in live resident bottlenose dolphins (*Tursiops truncatus*)in the eastern Gulf of Mexico, U.S.A. *Marine Mammal Science,* **24(4):** 831-844.

Goldsworthy, S.D., Page, B.C. 2007. A risk-assessment approach to evaluating the significance of seal bycatch in two Australian Fisheries. *Biological Conservation* **139**: 269-285.

Gordon, J., Leaper, R., Hartley, F.G. and Chappell, O. 1992. Effects of whale watching vessels on the surface and underwater acoustic behaviour of sperm whales off Kaikoura, New Zealand. *Science and Research Series* 52. Department of Conservation, Wellington, New Zealand, 64pp.

Grellier K. and Wilson B. 2003. Bottlenose dolphins using the sound of Barra, Scotland. Aquatic Mammals **29**, 378–382.

Gunnlaugsson, T. and Sigurjonsson, J. 1990. A note on the problem of false positives in the use of natural markings for abundance estimation. *Report to the International Whaling Commission,* Special Issue **12**: 143-145.

Ingram, S.N. 2000. The ecology and conservation of bottlenose dolphins in the Shannon Estuary, Ireland. PhD thesis, University College Cork, Ireland. 213pp.

Ingram, S.N., Englund, A. and Rogan, E. 2001. An extensive survey of bottlenose dolphins (*Tursiops truncatus*) on the west coast of Ireland. *Heritage Council Report no*. WLD/2001/42, 17pp.

Ingram, S.N., Englund, A. and Rogan, E. 2003. Habitat use, abundance and site-fidelity of bottlenose dolphins (*Tursiops truncatus*) in Connemara coastal waters, Co. Galway. *Heritage Council Wildlife Grant* #12314. 27pp.

Ingram, S. and Rogan, E. 2002. Identifying critical areas and habitat preferences of bottlenose dolphins (*Tursiops truncatus*). *Marine Ecology Progress Series* **244**: 247-255.

Ingram, S. and Rogan, E. 2003. Bottlenose dolphins (*Tursiops truncatus*) in the Shannon Estuary and selected areas of the west-coast of Ireland. *Report to the National Parks and Wildlife Service*, Ireland.28pp.

Irvine, A.B., Scott, M.D., Wells, R.S. and Kaufman, J.H. 1981. Movements and activities of the Atlantic bottlenose dolphin, *Tursiops truncatus*, near Sarasota, Florida. *Fishery Bulletin* **79 (4)**: 671-688.

Janik, V.M. and Thompson, P.M. 1996. Changes in the surfacing patterns of bottlenose dolphins in response to boat traffic. *Marine Mammal Science* **12(4):** 597-602.

Jepson, P.D., Bennett, P.M., Allchin, C.R., Law, R.J., Kuiken, T., Baker, J.R., Rogan, E. and Kirkwood, J.K. 1999. Investigating potential associations between chronic exposure to polychlorinated biphenyls and infectious disease mortality in harbour porpoises from England and Wales. *Science of the Total Environment* **243/244**: 339-348.

Kiszka, J.J., Hassani, S. and Pezeril, S. 2004. Distribution and status of small cetaceans along the French Channel coasts: using opportunistic records for a preliminary assessment. *Lutra* **47**: 33-46

Kruse, S. 1991. The interactions between killer whales and boats in Johnstone Straight, B.C. In: *Dolphin Societies: discoveries and puzzles* (eds, Pryor, K. & Norris, K.S.), University of California Press, Los Angeles, California, pp149-159.

Lacy, R.C. 1993. VORTEX: a model for use in population viability analysis. *Wildlife Research* 20: 45-65.

Leatherwood, S. and Reeves, R.R. 1983. The Sierra Club handbook of wwales and dolphins. Sierra Club Books, San Francisco.

Liret, C. 2001. Domaine vital, utilisation de l'espace et des ressources: les grands dauphins, *Tursiops truncatus*, de l'île de Sein. PhD thesis, University of Brest..

Liret, C., Creton, P., Evans, P.G.H., Heimlich-Boran, J.R. and Ridoux, V.1998. English and French coastal *Tursiops* from Cornwall to the Bay of Biscay, 1996. Photo-identification Catalogue. Project sponsored by Ministerede l'Environnement, France and Sea Watch Foundation, UK.

Lusseau, D. 2005. Residency pattern of bottlenose dolphins *Tursiops* spp. in Milford Sound, New Zealand, is related to boat traffic *Marine Ecology Progress Series* **295**: 265–272.

Lutkebohle, T. 1995. Dolphin movements and behaviour in the Kessock Channel and how these are influenced by Boat Traffic. *Scottish Natural Heritage, Review*, 37pp.

Marmontel, M., Humphrey, S.R. and O'Shea, T.J. 1997. Population viability of the Florida manatee (*Trichechus manatus latrirostris*), 1976–1991. *Conservation Biology* **11**: 467–481.

Moriarty, C. 1974. Studies of the eel *Anguilla anguilla* in Ireland. 3. In the Shannon catchment. *Irish Fisheries Investigations,* **14**: 1-25.

Moscrop, A. 1993. An assessment of threats to marine cetaceans resulting from the degredation of their habitats. MSc. Thesis, University of Greenwich, 228pp.

Murphy, S. and Rogan, E. 2006. External morphology of the short-beaked common dolphin *Delphinus delphis*: growth, allometric relationships and sexual dimorphism. *Acta Zoologica* (Stockholm) **87**; 315 – 329.

Ó Cadhla, O. Mackey, M., Aguilar de Soto, N., Rogan, E. and Connolly, N. 2004. Cetaceans and seabirds of Ireland's Atlantic margin. Report on research carried out under the Irish Infrastructure Programme (PIP): Rockall Studies Group (RSG) projects 98/6 and 00/13, Porcupine Studies Group project P00/15 and Offshore Support Group (OSG) project 99/38. 51pp.

Ó Cadhla, O., Englund, A., Philpott, E., Mackey, M. and Ingram, S.N. 2003. Marine mammal monitoring in the waters of Broadhaven Bay and Northwest Mayo: 2001-2002. *Report to Enterprise Energy Ireland Ltd*, 74pp.

O'Shea, T.J. 1999. Environmental contaminants and marine mammals. In: *Biology of marine mammals* (eds, Reynolds J.E. & Rommel, S.A.). Smithsonian Institution Press, Washington & London. pp485-564.

O'Sullivan, G. 1984. Seasonal changes in the intertidal fish and crustacean populations at Aughinish Island in the Shannon Estuary. *Irish Fisheries Investigation Series* B **28**: 3-15.

Otis, D.L., Burham, K.P., White, G.C. and Anderson, D.R. 1978. Statistical inference from capture data on closed animal populations. *Wildlife Monographs* **62**, 135pp.

Patterson, B.R., and D.L. Murray. 2008. Flawed population viability analysis can lead to misleading population status assessment: a case study for wolves in Algonquin Park, Canada. *Biological Conservation* **141**: 669-680.

Pesante, G., Evans, P.G.H., Baines, M.E. and McMath, M. 2008. Abundance and Life History Parameters of Bottlenose Dolphin in Cardigan Bay: Monitoring 2005-2007. *CCW Marine Monitoring Report* No. **61**. 81pp.

Pierce, G.J.. Santos, M.B .. Murphy, S. Learmonth, J.A. Zuur, A.F., Rogan, E. Bustamante, P., Caurant, F., Lahaye, V., Ridoux, V. Zegers, B.N., Mets, A., Addink, M., Smeenk, C., Jauniaux, T., Law, R.J., Dabin W., Lopez A., Alonso Farre, J.M.,. Gonzalez A.F., Guerra, A., Garcıa-Hartmann M., Reid, R.J., Moffat, C.F., Lockyer, C., Boon J.P. 2008 Bioaccumulation of persistent organic pollutants in female common dolphins (*Delphinus delphis*) and harbour porpoises (*Phocoena phocoena*) from western European seas: Geographical trends, causal factors and effects on reproduction and mortality. *Environmental Pollution* **153**, 401-415.

Ralls, K., Ballou, J.D. and Templeton, A., 1988. Estimates of lethal equivalents and the cost of inbreeding in mammals. *Conservation Biology* **2**:185-193.

Read, A.J., Drinker, P. and Northridge, S. 2006. Bycatch of marine mammals in US and global fisheries. *Conservation Biology* **20(1)**: 163-169.

Read, A.J., Wells, R.S., Hohn, A. and Scott, M.D. 1993. Patterns of growth in wild bottlenose dolphins, *Tursiops truncatus*. *Journal of Zoology* **231**: 107-123.

Rexted, E. and Burnham, K. 1991. User's guide for interactive programme CAPTURE. Colorado Cooperative Fish and Wildlife Research Unit. Fort Collins, CO, USA. 19pp.

Richardson, W.J., Fraker, M.A., Würsig, B. and Wells, R.S. 1985. Behaviour of bowhead whales *Balaena mysticetus* summering in the Beaufort sea: reactions to industrial activities. *Biological Conservation* **32:** 195-230.

Richardson, W.J., Greene, C.R., Malme, C.I. & Thompson, D.H. 1995. *Marine mammals and noise*. Academic press, London, 576pp.

Sergeant, D., Caldwell, D.K. and Caldwell, M.C. 1973. Age, growth and maturity of bottlenose dolphins (*Tursiops truncatus*) from northeast Florida. *Journal of the Fisheries Research Board of Canada* **30**: 1009-1011.

Seber, G.A.F. 1982. The estimation of animal abundance and related parameters. 2nd edition. Charles Griffin & Co. London, 654pp.

Thompson, P.M., Wilson, B., Grellier, K. and Hammond, P.S. 2000. Combining power analysis and population viability analysis to compare traditional and precautionary approaches to conservation of coastal cetaceans. *Conservation Biology*, **14(2)**: 1253-1263.

Turvey, S., 2007. First human-caused extinction of a cetacean species. *Biology Letters*, 3: 537 – 540.

Vargas, F.H., Lacy, R.C., Johnson, P.J., Steinfurth, A., Crawford, R.J.M., Boersma, P.D., and Macdonald, D.W. 2007. Modelling the effect of El Niño on the persistence of small populations: The Galápagos penguin as a case study. *Biological Conservation*, **137 (1)**: 138-148.

Wells, R. 2000. Reproduction in wild bottlenose dolphins: Overview of patterns observed during a long-term study, in Report from the Bottlenose Dolphin Breeding Workshop, Duffield, D.A., and Robeck, T.R. (Eds), American Zoological Association Marine Mammal Taxon Advisory Group, Silver Spring, MD, pp57-74.

Wells, R.S. and Scott, M.D. 1990. Estimating bottlenose dolphin population parameters from individual identification and capture-recapture techniques. *Reports of the International Whaling Commission, Special Issue* **12**: 407 – 415.

Wells, R.S., Allen, J.B., Hofmann, S., Bassos-Hull, K., Fauquier, D.A., Barros, N.B., DeLynn, R.E., Sutton, G., Socha, V. and Scott, M.D. 2008 Consequences on survival and reproduction of common bottlenose dolphins (*Tursiops truncatus*) along the west coast of Florida. *Marine Mammal Science*, **24 (4)**: 774-794.

Wilson, B., Hammond, P. and Thompson, P. 1999. Estimating size and assessing trends in a coastal bottlenose dolphin population. *Ecological applications* **9(1)**: 288-300.

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.

Wood, C.J. (1998). Movement of bottlenose dolphins around the southwest coast of Britain. *Journal of Zoology*, London, **246**: 155-163.

ACKNOWLEDGEMENTS

We would like to thank Roseanne Miller for all the hard work and long hours of boat driving during the fieldwork season of 2008. Thanks also to Mick Mackey for additional assistance in the field and to Laura Walshe for help with photo-id analysis. We are also grateful to Sue and Geoff Magee for help with sighting information and for their generous hospitality and to Simon Berrow for additional sighting information. We would finally like to thank the National Parks and Wildlife Services for commissioning this work and our thanks in particular to David Lyons and Eamonn Kelly for their support throughout the study.