Population status report for bottlenose dolphins using the Lower River Shannon SAC, 2006 – 2007

Final report to the National Parks and Wildlife Service

University College Cork
June 2007

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

ABSTRACT

We used standardised boat surveys and individual photo-identification to survey bottlenose dolphins (*Tursiops truncatus*) in the Lower River Shannon SAC between June 2006 and June 2007. A total of 29 surveys were conducted, resulting in 80 encounters with bottlenose dolphin schools. In total, approximately 182 hours were spent on the water with a total of 61 hours spent with dolphins. Photographs yielded 526 identifications of a minimum of 117 uniquely marked dolphins. Of these, 43 had permanent natural marks, 39 had temporary marks and 35 had superficial marks.

The dolphins show long term site fidelity in the Shannon. Of 43 permanently marked dolphins photographed during 2006/7, 22 were initially identified in 1996/7 when UCC dedicated surveys commenced. Dolphin schools were encountered throughout the survey area with little seasonal or individual variation. Kernel analyses of sightings locations of 369 dolphin schools encountered since 1996 identified two hotspots of activity at the Estuary mouth and near Money Point. There was little difference in geographic distribution of dolphins within the SAC between summer and winter encounters, although there was a seasonal decrease in numbers between January and April. School sizes ranged between one and 38 with a median school size of six. Plotted distributions of encounter locations showed some habitat partitioning between identified individuals. Of 82 marked dolphins, 57 were never encountered in the upriver parts of the Shannon, whereas six individuals were only sighted in these upper areas. A total of 19 individuals were encountered in inner and outer parts of the study area.

We used a subset of surveys during a period of peak use to estimate the abundance of dolphins using the outer Estuary. Photo-identification data from 16 surveys conducted between June and November 2006 were used in a mark-recapture procedure. We selected high quality images (approximately 45% of all photographs) of well-marked individuals (approximately 60% of all dolphins) for the mark-recapture model. The resulting estimates for left side and right side identifications were inflated according to the calculated proportion of marked dolphins in the population and combined using inverse variance weighting to produce an estimate of 140 ±12 (SE) dolphins (CV=0.08, 95% CI 125-174). This estimate compares with an estimate of 121 ±14 (SE) (CV=0.12 95% CI 103-163) from 2003 and 113 ± 14 CV=0.14 95% CI 94-161) from 1997.

This series of estimates indicates a likely population increase in the Shannon and using the current estimate CV value we examined the sensitivity of these surveys to detect a hypothetical population change in the Shannon SAC with different reporting frequencies and different rates of population change. Using the current triennial reporting strategy estimates of the current precision will detect a 5% annual population change within 12 years. Given the importance of estimate precision on the sensitivity of monitoring surveys we used survey data from 2003 to examine the effect of increased sampling rate on estimate precision (CV values). We estimate that at least 12 surveys of the outer Estuary with approximately 2 sightings of each recorded dolphin are sufficient to produce a reliable and robust estimate with an associated CV <0.12. We 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 250 year period in the absence of a major catastrophe. However, the probability of extinction was found to increase if conservation action was delayed until population declines were detected through monitoring.

Survey effort continued throughout the winter months to examine changes in distribution patterns and the number of animals using the Estuary throughout the year. It was found that a large number of animals were still present during October and November, while fewer animals were recorded during January to April 2007. Dolphins were sighted throughout the study area for the winter months and individual ranging patterns did not change markedly over time.

INTRODUCTION

Bottlenose dolphins (*Tursiops truncatus*) are found in temperate and tropical seas worldwide. It is one of 24 species of cetacean recorded in Irish waters (Berrow and Rogan, 1997, Ó Cadhla *et al*., 2004, Wall *et al.,* 2006). They are found in pelagic waters, although more commonly encountered in shallow coastal habitats including inlets, bays, lagoons, estuaries and rivers (Leatherwood and Reeves, 1983).

With their robust body shape and a relatively short beak bottlenose dolphins are not easily confused with any other dolphin species found in Irish waters (Plate 1). They exhibit sexual dimorphism with males larger than females and are long-lived animals with a life expectancy of up to approximately 50 years (Read *et al.,* 1993). Female bottlenose dolphins reach sexual maturity around 10 years of age (Sergeant *et al.*, 1973). After a 12-month gestation period they give birth to calves of approximately 1m in length that suckle for 1.5 to 2 years (Leatherwood and Reeves, 1983). Adult bottlenose dolphins in Ireland are a large ecotype and commonly reach approximately 4m in length (Rogan unpublished data).

Plate 1. A juvenile male bottlenose dolphin illustrating the robust body shape, dark grey coloration and paler underside.

Bottlenose dolphins are widespread in the coastal waters of western Ireland (Ingram *et al*., 2001) with the largest resident population of dolphins in Irish waters found in the Shannon Estuary, a critical habitat for this species (Ingram and Rogan, 2002). Recent studies have indicated some degree of site fidelity 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; Ó'Cadhla *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 the only Special Area of Conservation 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, 1998; Liret, 2001; Kiszka *et al*., 2004) and the Sado Estuary, Portugal (dos Santos and Lacerda, 1987). Two SACs have been designated in Britain, in the Moray Firth in Scotland, with a population of about 129 dolphins (Wilson *et al*., 1999) and Cardigan Bay in Wales with a population of 213 individuals (Baines *et al.,* 2002).

Effective management and conservation requires up-to-date knowledge of population size and ranging patterns. This type of information is vital to detect trends in numbers, changes in distribution or use of habitat. Information on spatial and temporal variation in abundance is also necessary to determine whether management actions are needed and the effectiveness of any such actions that are implemented (Evans and Hammond, 2004).

Bottlenose dolphins using the Shannon are 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); 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; 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 in the outer Estuary. 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 by UCC for the last ten years shows long-term site fidelity and seasonal residency of dolphins using the Shannon Estuary (Ingram, 2000; Ingram and Rogan, 2002). The majority of dolphins identified during a census in 2003 had been known since the project began in 1996 (Ingram and Rogan*,* 2003). Some coastal bottlenose dolphins found in other areas have been found to migrate (Barco *et al*., 1999; Hubard *et al*., 2004) and previous surveys have indicated similar trends for the Shannon Estuary where the number of dolphins present decreases during the winter months (Ingram, 2000). We examined the long-term site fidelity of dolphins catalogued in the Shannon Estuary since 1996.

Abundance of the Shannon dolphin population

There are several methods for deriving abundance estimates for cetacean populations including shore, boat or aircraft surveys (for review see Evans and Hammond, 2004). Shore watches with multiple observers and synchronised counts can provide representative coverage of areas and allow minimum abundance estimates to be derived (Hammond and Thompson, 1991, Berrow *et al*., 1996). Line-transect surveys using dedicated platforms with double platforms are commonly used to derive abundance estimates for cetaceans at sea (Hammond, 1986; Evans and Hammond 2004). Multiple sample, capture-mark-recapture methods are increasingly used for estimating population size using photo-identification of recognisable individuals (Evans and Hammond, 2004). This approach can provide very accurate estimates and also offer a measure of precision. Mark-recapture estimates are more accurate if a large proportion of the population is photographed and models are available that reduce problems of heterogeneity of capture probabilities arising from inter-individual and inter-survey differences. Previous assessments of abundance using mark-recapture modelling of individual photo-identification data of the Shannon dolphin population have been calculated in 1997 (Ingram, 2000) and in 2003 (Ingram and Rogan*,* 2003) providing estimates of 113 ±16 (se) and 121 ± 14 (se) respectively. The work presented here includes an updated abundance estimate for the bottlenose dolphins of the Lower River Shannon using photo id and mark-recapture methods.

Ranges of known dolphins

Sightings of dolphins occur throughout the study area, but are not evenly distributed. Two critical areas have been identified within the Shannon Estuary (Figure 1) using harmonic mean transformation of encounter locations (Ingram and Rogan, 2002). The western of these two areas is situated at the mouth of the Shannon and the eastern area in the up-river part, close to Tarbert and Moneypoint (Figure 1). The known ranges of individuals were found to differ with some animals only sighted in the up-river part of the study area. All animals sighted 5 or more times were found to be using at least one or both of the two core areas identified and 95% of the animals had ranges including the western critical area (Ingram and Rogan, 2002). Here we use over a decade of dedicated survey data to examine long term ranging patterns of individuals within the SAC.

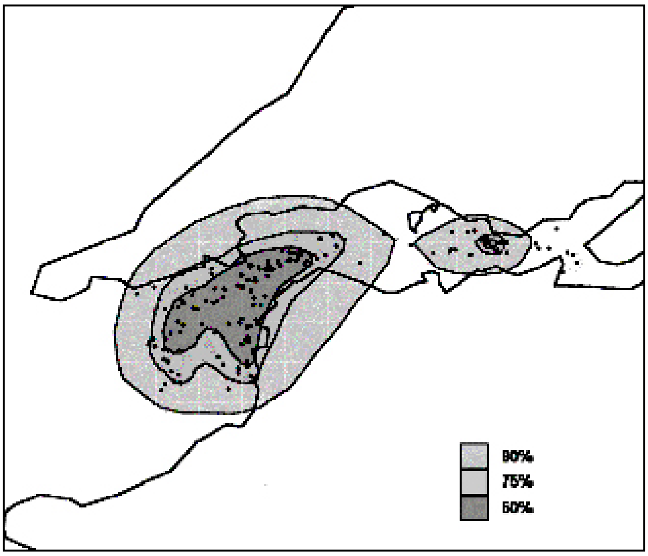

Figure 1. Critical areas for bottlenose dolphins in the Shannon Estuary (from Ingram and Rogan, 2002).

Population viability analysis

Small populations are more likely to go extinct than larger ones and are vulnerable to loss of genetic variability, the Allee effect and inbreeding depression (e.g. Ralls *et al.*, 1988). In addition, they are susceptible to changes 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 (e.g. 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. Each PVA is individually developed for a target population or species using parameters calculated with population specific data. The larger goal in mind when conducting a PVA is to ensure that the population of a species is self-sustaining over the long term and modelling the predicted effects of simulated catastrophic events. PVA uses historical and current conditions to predict future outcomes; thus, the accuracy of PVA decreases with increasing extrapolated time. It is approximated that PVA projections are valid for 5-10% of the length of the dataset. A key function is to identify factors that have maximum affects on pushing a population towards extinction and thus aiding conservation managers to mitigate for these factors. PVA can be used to model population viability under different management regimes (Thompson *et al*., 2000)

PVA models are subject to the following assumptions:

- All animals have identical life histories (i.e. same age of first breeding, reproductive lifetime etc).
- All animals belong to a single closed population.
- There is equal sex ratio.
- The population has a stable age distribution.

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

Project aims

This project aimed to:

- calculate an abundance estimate for bottlenose dolphins using the lower river Shannon SAC during 2006,
- use long term data to assess long term site fidelity and ranging patterns of marked animals in the outer Estuary,
- examine the relative abundance and distribution of dolphins in the Shannon SAC throughout the year and to examine distribution patterns during the winter and summer months,
- use previous survey data to optimise estimate precision,
- examine the sensitivity of current reporting strategy to population trend detection. Model population viability analysis (PVA) to examine the long term stability of this population.

METHODS

Boat based photo-identification surveys

Dolphin surveys of the outer Shannon Estuary were conducted using a 5.8 m rigid hull inflatable boat (RIB), between June 26th 2006 and June 6th 2007. The surveys followed a standardised 80km route used by UCC for dolphin surveys since 1996 (Figure 2). The study area included regions of known dolphin abundance (Ingram and Rogan, 2002) and included areas used by commercial dolphin watching tour boats (Berrow and Holmes, 1999).

At least two surveys were attempted for each month of the study period. All surveys were conducted in Beaufort sea-state three or less and suitable light conditions to minimise effects of sea-state on the probability of sighting and obtaining useful identification photographs of dolphins. Occasionally surveys were abandoned due to deteriorating weather conditions. Survey speed was generally kept at approximately 20kmh but was lowered if conditions so required (i.e. in swell or higher sea state).

During surveys, the route was followed until a group of dolphins were sighted. A dolphin school was defined 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). The number of animals present was estimated and the presence of juveniles, calves or neonates 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, 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 when strong avoidance behaviours 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.

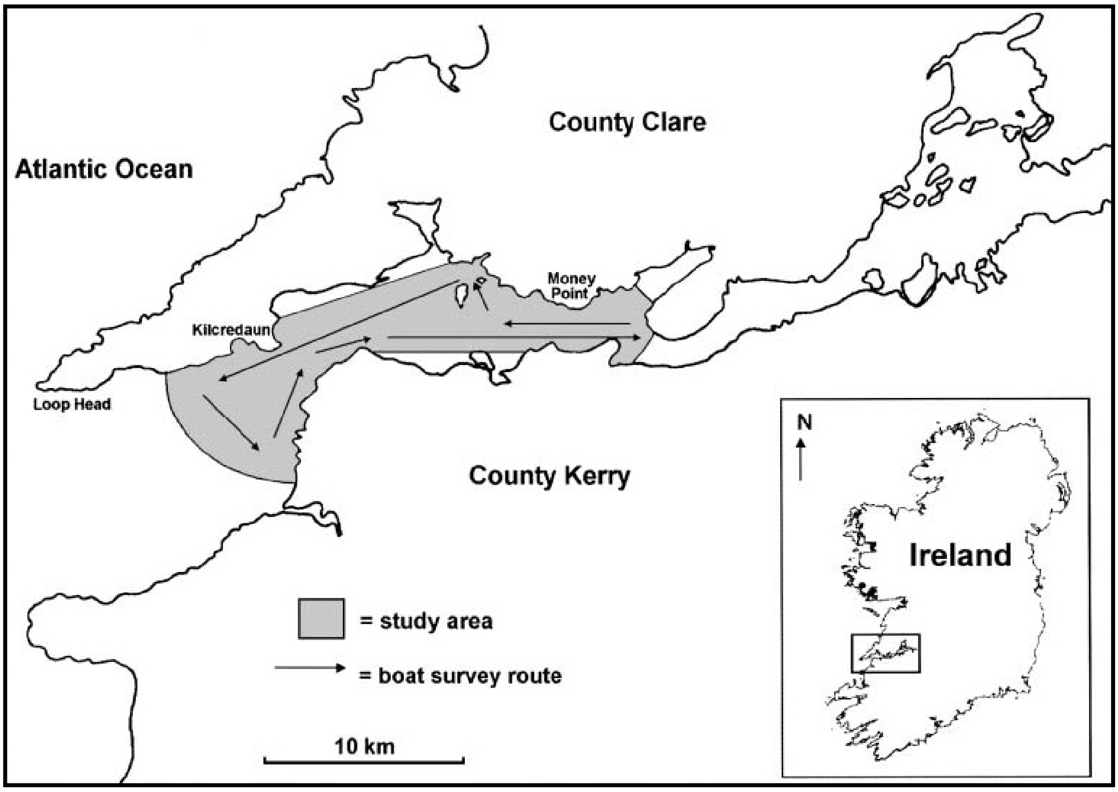

Figure 2. Map showing the study area and survey route.

Photograph analysis

The best photographs of each side of every dolphin identified from each encounter were selected. The quality of these photographs was then scored from 1 to 3 (Table 1) 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. Since it was not always possible to match left with right identifications and since photographs were frequently only obtained from one side, there were effectively two separate catalogues of “right side” and “left side” identifications.

Table 1. The criteria used to score the quality of dorsal fin id-photographs of (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 out of focus photograph, or photo taken at acute angles of the fin

Severity of identifying marks

A wide variety of 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. 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 2a). Dolphins with minor fin damage and/or deep tooth rakes were assigned as grade 2 (Plate 2b). Dolphins with superficial scratches and skin lesions were assigned as grade 3 (Plate 2c).

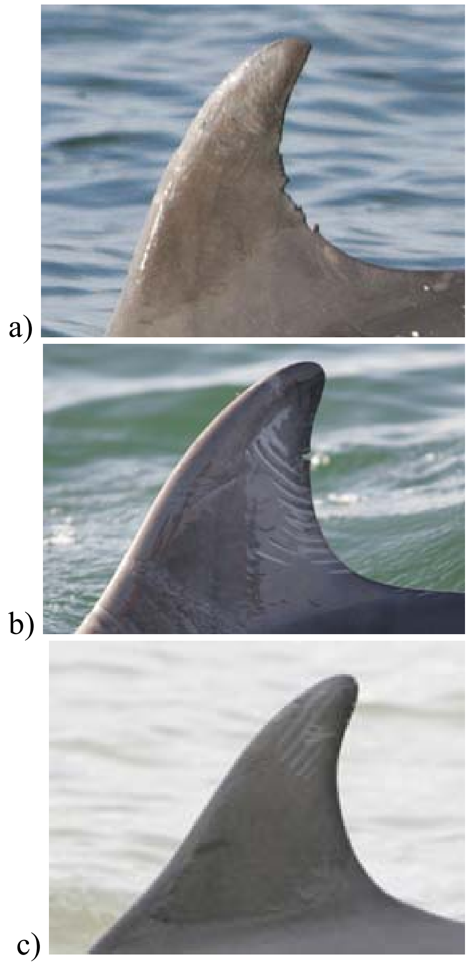

Plate 2. Examples of dolphin fins showing the three grades of mark severity used in analysis. Each dolphin was graded from one to three as follows: a) an example of a fin with grade 1 marks, consisting of significant fin damage or deep scarring that were considered permanent; b) temporary, grade 2 marking 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 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 on four or more times in 2006-07 with previous sightings data since 1996.

Seasonal habitat use patterns

We investigated the seasonal distribution of dolphins in the SAC by plotting monthly encounters throughout 2006-7. To examine long-term seasonal differences in habitat use we compared the locations of all encounters since 1996 during summer months (May to September) with encounters during winter months (October to April). We used kernel plots to identify 'hot spots' of dolphin habitat use within the outer Estuary during the summer and winter periods.

Capture-recapture abundance analysis

Data from photo-identification were used to model the abundance of dolphins in the Shannon using 'mark-recapture' software CAPTURE (Rextad and Burnham, 1991). Multiple sample capture-recapture abundance estimates of closed populations 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

Assumption 1 refers to geographic and demographic closure in which there is no immigration or emigration in the population or changes due to birth or death or change of marking during the course of sampling. The relatively short duration of the sampling period included in the capture recapture 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 (score of 3) and poorly marked grade 3 animals (see Plate 2) were excluded from capture-recapture analysis.

Consequently, the dolphins included in the mark-recapture analysis represents 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.

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. The best quality (grade 1) photographs 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:

$$N = \frac{Nhat}{\theta}$$

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

The variances of the total estimates (varN) were obtained using the delta method as follows:

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

Separate estimates for right side and left side identifications were calculated and these were then combined using and inverse variance weighted average producing an overall population estimate (Wilson *et al*., 1999).

Modelling optimal monitoring protocols
Data from the 2003 abundance estimate (Ingram and Rogan, 2003) were used to model the effect of increased survey effort on the precision of resulting abundance estimates. The aim was to estimate the optimal number of surveys required to obtain a robust estimate with an acceptable CV.

To examine the effects of different levels of sampling effort on resulting estimates we used a step-wise iterative permutation procedure to run CAPTURE with data from increasing numbers of surveys. At the first step we used data from 3 surveys and ran capture using sightings data from all combinations of three surveys. At each step we increased the number of surveys included in the estimates and ran CAPTURE using all possible combinations of available sightings data. We conducted this procedure using left side only identifications from 3 surveys to the total of 14. From the output files we calculated mean sighting frequencies of individual dolphins at each step as a measure of sampling effort with increasing numbers of surveys. We examined the resulting estimates and associated CV values obtained from permutations with increasing numbers of surveys. To examine the effect of increased survey effort on the discovery rate of previously unrecorded marked animals we examined the mean values of the number of animals included in iterations with increasing numbers of surveys. In addition we used a power analysis (Gerrodette, 1987; Thompson *et al*., 2000) to examine the sensitivity of different monitoring regimes to detect different rates of population decline.

Population viability analysis
We used VORTEX (version 9.72. Lacy, 1993) to carry out a range of simulations under four scenarios. In two models the estimate derived from the 2006 mark-recapture analysis was used as the initial population size (140 dolphins). We ran the model allowing zero or one catastrophe (1% of years) using a 250year timeframe and 1000 iterations. We also ran two simulations with a start population of 76 individuals, calculated to be the number of individuals remaining in a population after detection of a 5% per year rate of decline under the current management regime of 3 surveys per year and again ran the simulation with one and zero catastrophes.

Despite the long-term nature of this study, there are sufficient gaps in the data (years and/or months missing) to prevent us, at this time, from deriving our own estimates of reproductive parameters for this population. Following Thompson *et al*., 2000 we therefore used published data for input parameters where necessary and these are summarised in Table 2.

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	140 and 76	
Carrying capacity	280 (EV 10)	

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.

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. We set carrying capacity as twice the current population and for these simulations, extinction was defined as when there were less than 10 animals remaining.

RESULTS

Survey effort

A total of 29 photo-identification surveys were conducted between June 26th 2006 and June 6th 2007 (Table 3) totalling 182 hours spent on the water. All survey days except three resulted in completed or 'full' surveys covering the entire survey route in good weather and sea conditions (Figure 3). The remaining were either cancelled before the survey route was completed or part of the route was excluded due to deteriorating sea conditions. One incomplete survey, (# 102) was excluded from all further analyses.

Table 3. Survey date, number of schools encountered and number of dolphins counted in those schools (part: 106 and 120 and cancelled: 102 surveys are indicated with an asterisk).

Date of survey	Survey number	Number of schools encountered	Number of dolphins identified
June 26th	99	3	14
July 15th	100	5	38
July 17th	101	3	30
July 26th *	102	1	0
August 7th	103	8	34
August 21st	104	4	29
September 12th	105	4	23
September 17th *	106	2	9
September 25th	107	2	8
October 3rd	108	2	17
October 4th	109	1	12
October 20th	110	4	71
October 23rd	111	3	21
October 29th	112	1	22
November 1st	113	1	32
November 3rd	114	5	35
November 4th	115	3	58
January 23rd	116	5	7
January 25th	117	3	21
January 26th	118	0	0
February 5th	119	2	9
February 17th *	120	5	41
March 23rd	121	2	20
March 26th	122	0	0
March 27th	123	1	22
April 4th	124	0	0
April 6th	125	2	12
April 18th	126	5	36
June 6th	128	3	19
Total		**80**	**640**

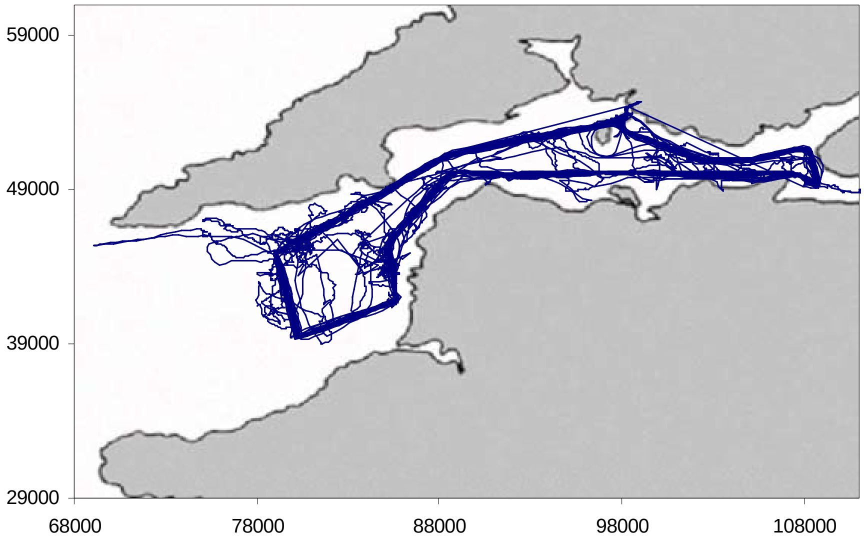

Figure 3. Map showing all survey tracks completed during the survey period. The axes show metric OSI easting and northing.

Dolphin encounters

A total of 80 encounters with bottlenose dolphins were recorded on 26 days. No other species of cetacean was observed during the study period. Bottlenose dolphins were found throughout the study area. School sizes ranged from 1 to 38 individuals with a median school size of 6. Five of the encounters were with lone animals and six encounters included more than 20 individuals. No dolphins were encountered during three of the surveys.

Seasonal trends in distribution and abundance

Dolphins were encountered during each month of the study (Figure 4) and no change was found in the distribution of encounters between the months surveyed in 2006-7 (Figure 5) with dolphin schools distributed throughout the survey area.

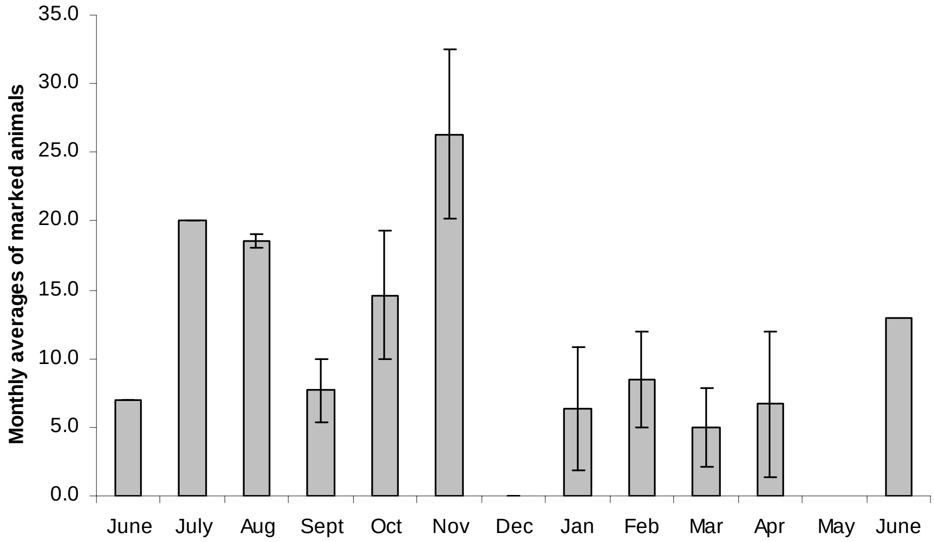

Figure 4. Mean number of marked dolphins identified in the outer Estuary per month (± SE).

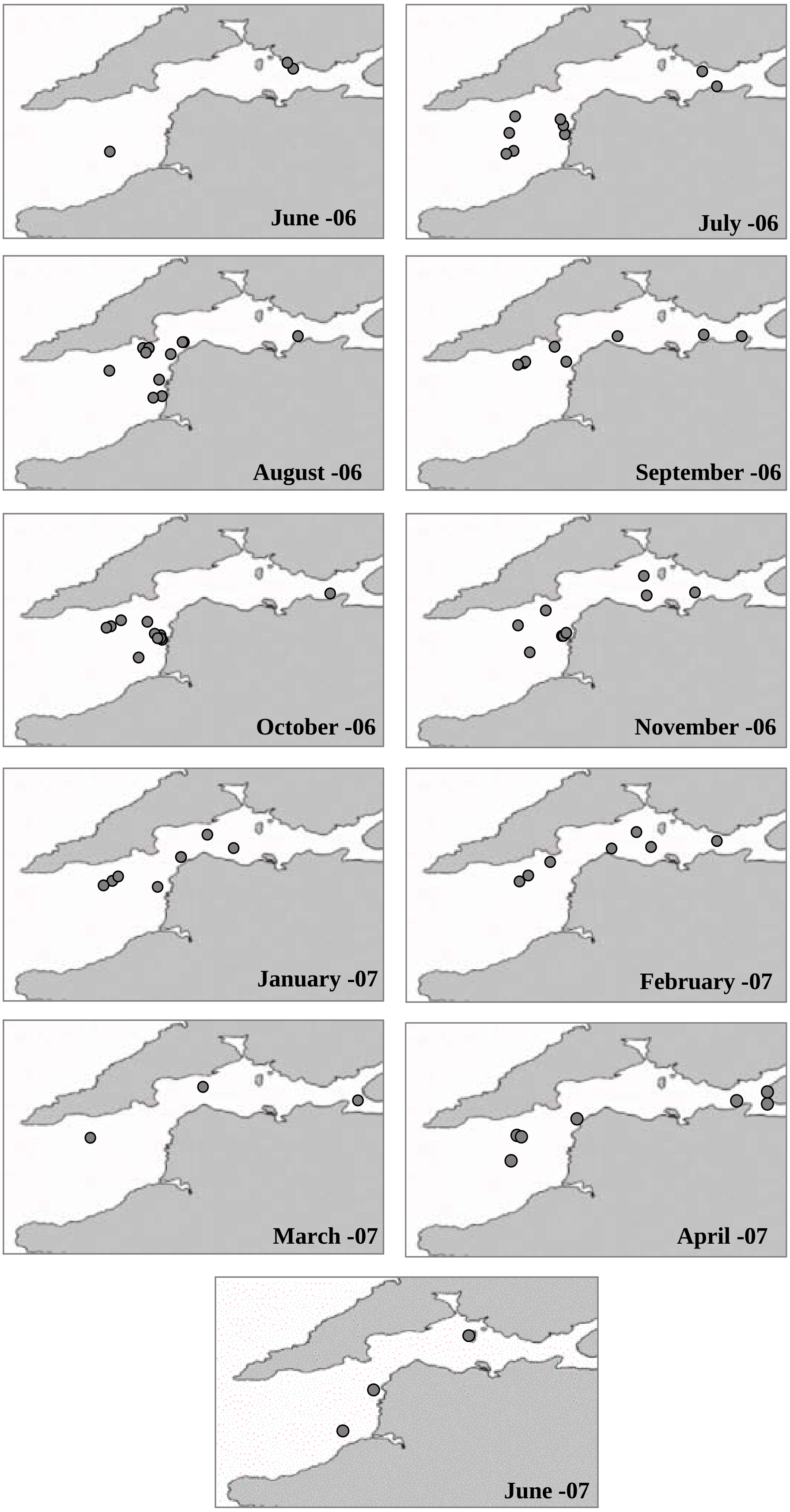

Figure 5. Monthly distribution of encounter locations for the study period June 2006 to June 2007.

A kernel analysis of the distribution of encounter locations during the summer months during 1996 to 2007 showed two concentrated areas of intense use (Figure 6a). One of these located at the Estuary mouth near Kilcredaun and one off Money Point. There was no apparent difference in the distribution of winter encounters (Figure 6b) with dolphins appearing to use the whole of the lower Estuary, year round.

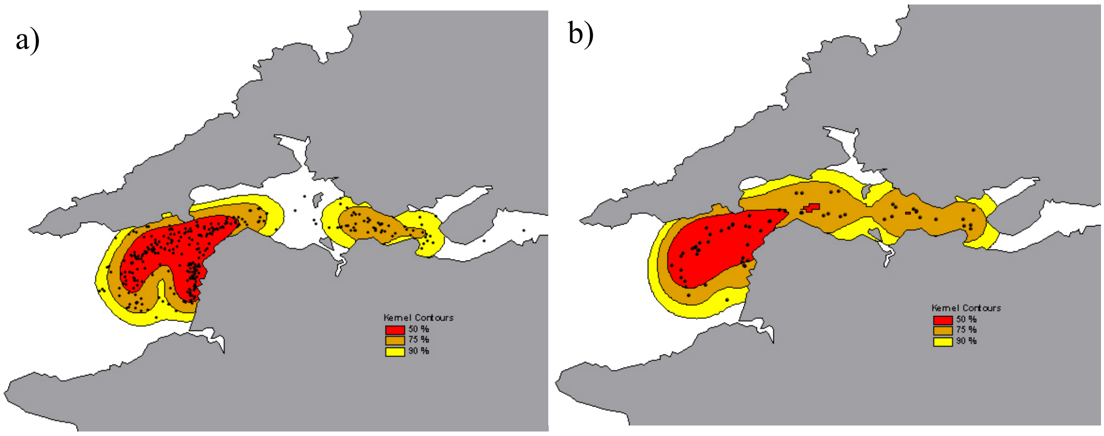

Figure 6. Kernel analysis contour plots showing areas of concentrated use in the outer Estuary from 1996 to 2007 during (a) summer months (May to September, n=304); b) winter months (October to April, n=64). Contours show the areas containing 90% (yellow), 75% (brown) and 50% (red) of all encounter locations. Black dots show encounter locations.

Results of photo-identification analysis

During the survey period a total of 5,630 photographs were taken of bottlenose dolphins in the Lower Shannon Estuary. These photographs yielded 508 identifications of individual dolphins. Out of these, 56 dolphins were identifiable from both sides of their dorsal fins, 112 were identified from their left side and 100 from their right side (Table 4). The frequency of sightings of identified dolphins ranged from 42 individuals that were only sighted in one of the 12 survey months to one animal (# 101) that was seen in 8 of the study months. The majority of dolphins sighted only once had superficial marks (Figure 7).

Table 4. Number of dolphins identified from their left side, right side and from both sides. These identifications were made from high quality photographs (quality 1 or 2). The degree of mark severity of identified dolphins is also shown.

	Mark severity			
Side	**Permanent marks**	**Temporary marks**	**Superficial marks**	**Totals**
Both	25	17	14	56
Left	43	36	33	112
Right	43	27	30	100

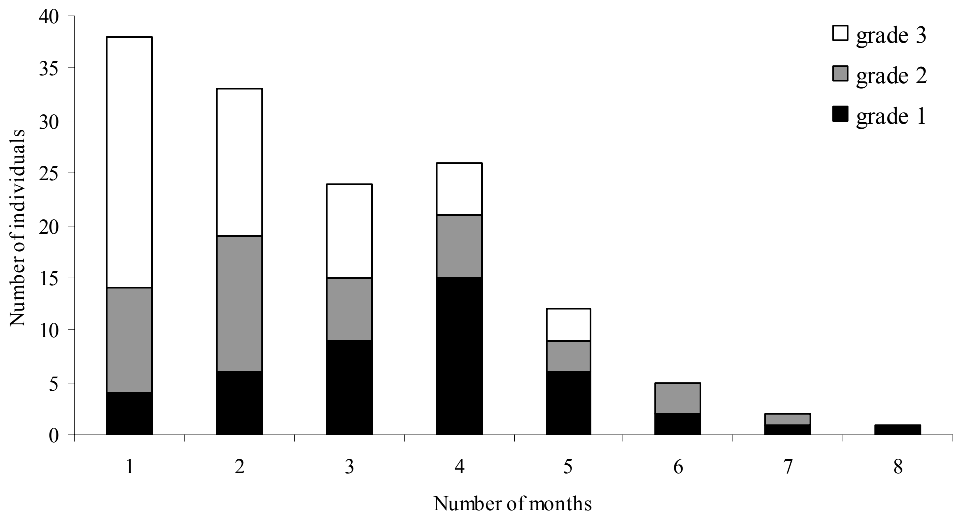

Figure 7. The number of months throughout the year-long study during which individual dolphins were sighted and their degree of marking.

Level of disturbance

Evasive behaviour such as aggressive approaches or rapid avoidance was rarely observed during the course of the study. On occasions when such behaviour was recorded, the survey team would follow protocol and remain at least 50m from the dolphins for at least five minutes. If the behaviours continued when the encounter was resumed, then the encounter would be terminated and the survey route continued. Some degree of evasive behaviour was noted during 13 of the encounters (16% of all, n = 80). For four of these, the encounter was resumed and the dolphins showed no negative behaviours and were even approaching the survey vessel. On one occasion the survey boat maintained a distance of over 50m and contact with the dolphin school was subsequently lost due to poor sea conditions. Total encounter time ranged between 5 and 216 minutes with a median of 35 minutes.

Sightings of juveniles, calves and neonates

Juveniles (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. In total, 45 juveniles and 34 calves were observed (including 7 neonates). Four of presumed mothers of neonates photographed had only superficial dorsal fin marks (grade 3) and were not known from previous years (Table 5). One previously known female (# 19) was seen with a larger juvenile at the start of the survey period and with a neonate in October. Calves are rarely sufficiently marked for repeated identification.

Plate 3. Calf with foetal fold lines on its flank.

Table 5. Date of first sightings of neonatal calves during 2006 and 2007. Animals without identifying marks are denoted with an asterisk.

Date of first sighting	Escorting adult #	Degree of marking of escorting adult
Aug 7th 2006	*	3
Sept 17th 2006	145	1
Sept 17th 2006	*	3
Oct 20th 2006	*	3
Oct 20th 2006	286	1
Oct 23rd 2006	19	1
Nov 4th 2006	557	3

Sightings of permanently marked dolphins

There were a total of 43 permanently (grade 1) marked dolphins identified during the survey period (Figure 8). Of these, 27 were identified from their left side, 33 from their right side and 39 from both sides. Three of these individuals were not previously catalogued (#s 533, 536, and 544).

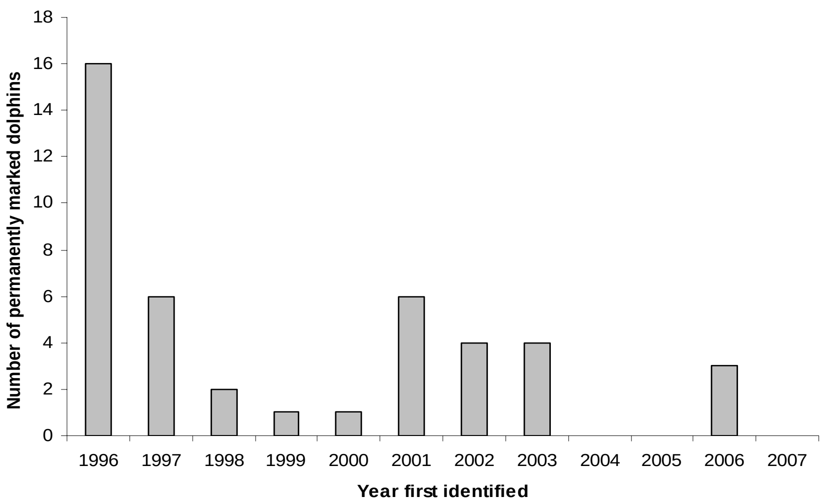

Figure 8. Number of permanently marked dolphins sighted during the study period and the year of their first identification.

Ranging patterns of permanently marked dolphins

Of all permanently or temporarily marked animals (n=82), 58 were only recorded in the outer parts of the Estuary, six were sighted only in the up-river part of the Estuary and 19 individuals were observed using the entire study area. The ranges of animals recorded on four times or more show a use of one or both core areas that were identified in 2002 (Figure 9). The ranges correlate well for those animals previously known and recorded on more than four occasions on previous surveys in the area (1996 to 2003).

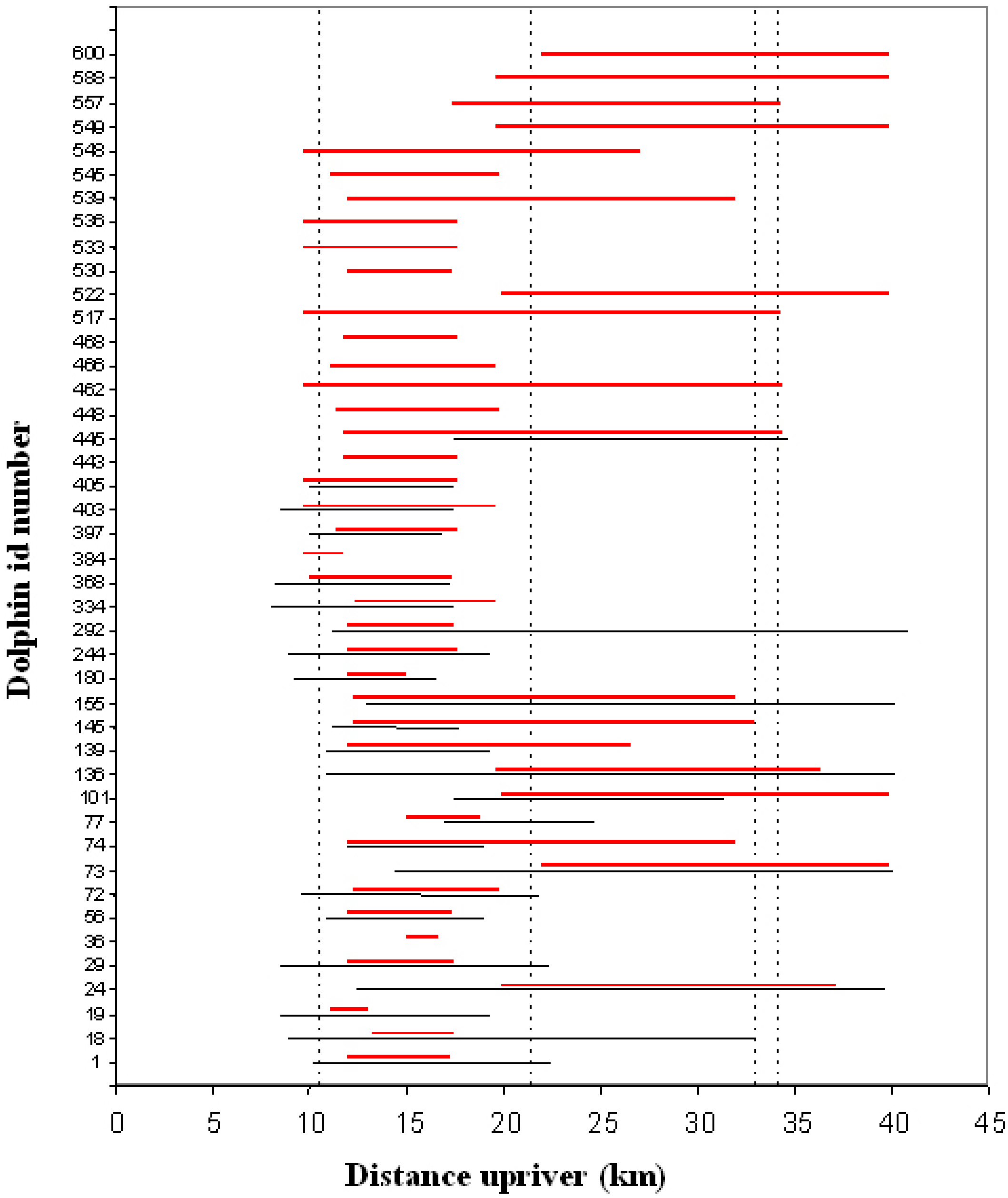

Figure 9. The longitudinal ranges of marked animals sighted four or more times during the survey of 2006-07 presented as red horizontal lines. Individuals that were also recorded on four or more occasions during previous years are presented as black lines for comparison.

Mark-recapture estimate

The rate of 'discovery' of well-marked individuals was found to steadily decrease throughout the study (Figure 10) with no new individuals being catalogued after the last mark-recapture survey in November, indicating the population was closed during the mark-recapture sampling period. The dataset used in capture-recapture analysis included 188 sightings of 78 marked individuals (68 known from their left and 57 from their right).

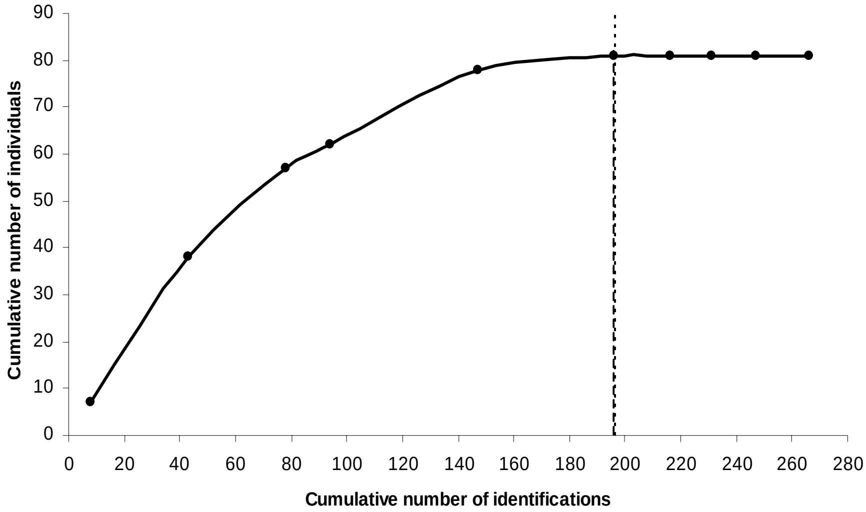

Figure 10. Discovery curve showing the cumulative number of individuals identified with increased survey effort. The dotted line indicates the limit of survey effort included in the mark-recapture analysis.

The sightings histories of marked dolphins encountered during the sampling period (Table 6) show no indication of structured migration into or out of the Shannon during the mark-recapture sampling period. This again indicates that the population was closed during sampling.

Table 6. Sightings of individual dolphins during each month of the capture-recapture procedure. Dolphin id numbers are listed in order of first sighting date and grey shading indicates presence during each month.

Dolphin id	June	July	August	September	October	November
1	■				■	
101	■	■	■	■	■	
136	■		■		■	
180	■				■	
244	■	■			■	■
292	■	■	■		■	
335	■				■	■
19		■			■	
24		■	■	■		
29		■		■	■	
34		■				
56		■		■	■	■
139		■		■	■	■
302		■			■	■
320		■			■	
340		■			■	
384		■	■			■
397		■	■		■	■
405		■	■		■	■
413		■				■
419		■				
433		■	■			■
443		■	■			■
445		■	■		■	
448		■	■		■	■
453		■				■
462		■	■			■
466		■			■	■
467		■	■			
468		■	■			■
514		■				■
527		■				■
533		■			■	■
535		■				■
536		■			■	■
545		■			■	■
578		■			■	■
18			■		■	
36			■		■	
72			■		■	
73			■		■	
74			■	■	■	■
81			■			
134			■			■
155			■			■
279			■			■
368			■	■	■	■
382			■			
398			■			
425			■			■
428			■		■	■
539			■	■	■	■
544			■			■
548			■		■	
560			■		■	■
145				■	■	■
282				■	■	■
372				■		
547				■		
222					■	
286					■	
334					■	■
402					■	■
403					■	■
412					■	
414					■	
478					■	■
491					■	
517					■	■
532					■	
567					■	■
570					■	■
588					■	
447						■
573						■
574						■
581						■

Estimates of number of marked dolphins using the Shannon

Estimates of abundance were calculated using left side and right side identifications separately (Table 7). CAPTURE model M_{th} (Chao *et al.,* 1992) was used since it is robust to heterogeneity of capture probabilities between individual animals and between surveys.

Table 7. Results of abundance estimates of marked dolphins from left side and right side identifications, n is the number of identified dolphins and Nhat the estimated total number of marked dolphins.

Side	n	Nhat	se	cv	95% confidence intervals
Left	76	86	5	0.17	80-100
Right	75	92	8	0.14	83-114

Estimate of the total number of dolphins using the Shannon

The values of Nhat for left and right sides obtained from capture were increased according to the proportion of marked dolphins in the population (θ) (Table 8).

Table 8. 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.

Side	Total number of ids	Number of ids of marked animals	Proportion of animals with marks, θ
Left	261	166	0.64
Right	190	116	0.61

Left side and right side estimates were combined using an inverse variance weighted average to give a total estimate of 140 ± 12(SE) CV=0.08, 95% CI 125 - 174.

Sampling effort permutation analysis

We ran a total of 16,189 estimates using CAPTURE model M_{th} with left side identifications with all combinations of 2003 sightings data from 3 to 14 surveys. From the model outputs we computed the mean values for the resulting estimates, associated CV values and mean individual capture rates at each level of the procedure with 3 surveys, four surveys and so on.

Sampling rates

The mean sighting frequency of marked dolphins increased linearly with survey effort (Figure 11) indicating little difference in the capture rates between surveys and minimal between-survey heterogeneity. Mean individual sighting frequency increased from 1.17 when data from 3 surveys were included to 2.17 when data from all 14 surveys were included.

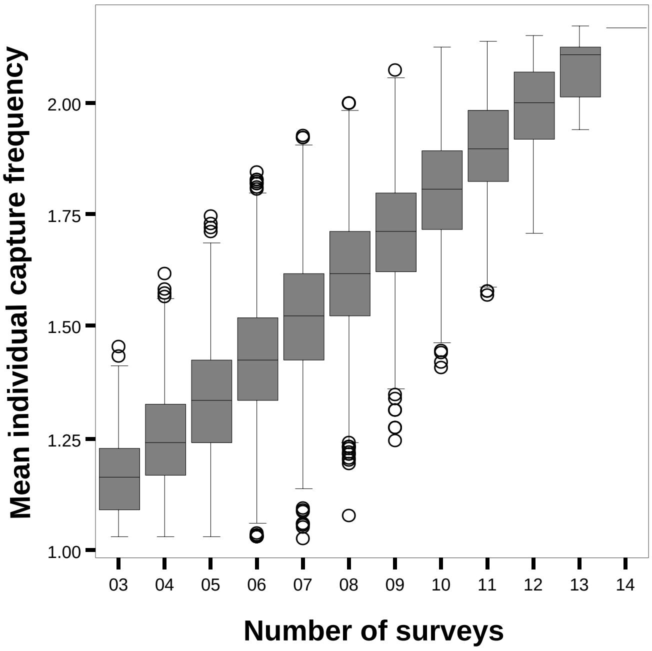

Figure 11. The mean individual capture frequencies with increasing survey effort.

Estimate size and CV values

The average estimate values changed little with increased survey effort (Figure 12) but the range of possible estimates was reduced with more surveys indicating an increase in the degree of accuracy of estimates with increasing survey effort. A reduction in estimate CV values indicated an increase in precision of estimates with increased survey effort (Figure 13). With data from 3 surveys we found a median value of 0.58 for estimate CV s reducing to 0.12 when all survey data were included. With 12 surveys the median CV value dropped to below 0.13 with all permuted values below 0.2.

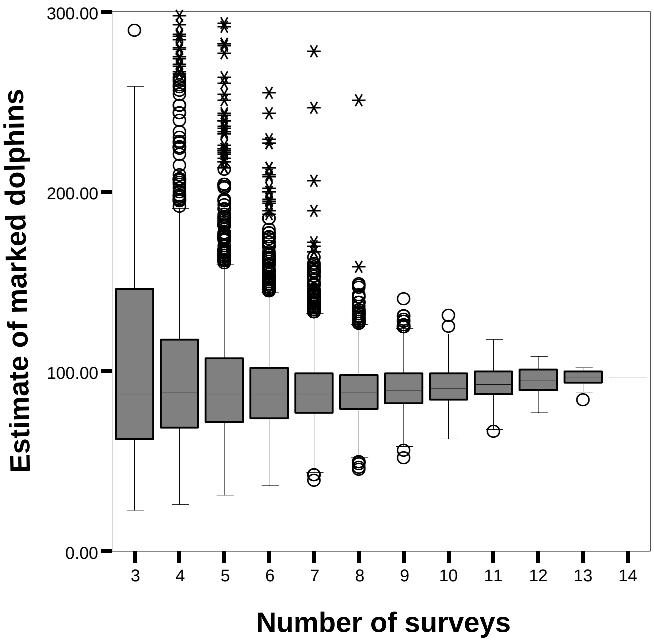

Figure 12. Estimates of the numbers of marked dolphins obtained with inclusion of increasing survey effort.

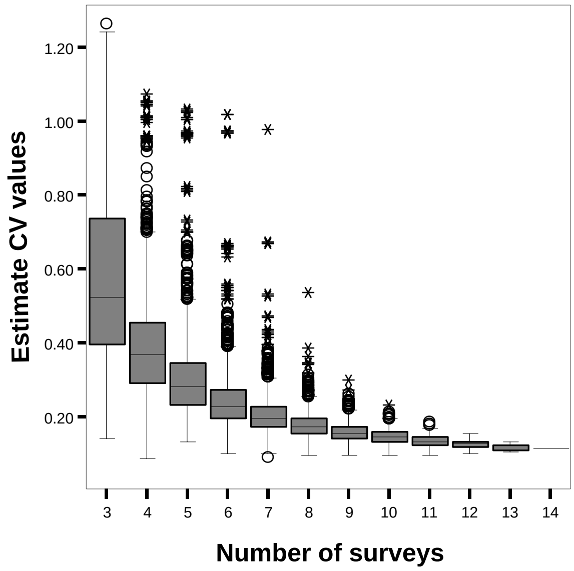

Figure 13. Mean CV values for estimates obtained from mark-recapture analysis using data from increasing numbers of surveys.

Detecting population change

Using the CV values obtained in estimates calculated during 1997, 2003 and 2006 we used a power analysis to predict the time taken to detect different hypothetical rates of population change using the current triennial reporting strategy (Figure 14). The importance of low CV values is demonstrated with a marked improvement in power to detect population change with CV values below 0.1. We also examined the power of different reporting rates to detect a hypothetical population change of 5% per annum with different estimate CVs (Figure 15). Using the current triennial reporting procedure, and with the current estimate precision a 5% per year population change will not be detected until four reporting cycles (i.e. 12 years). In this scenario using present reporting procedures, the population will have declined to approximately 76 dolphins before detection. An annual reporting cycle will detect the same rate of population change within 7 years and a six yearly reporting cycle will not detect this change until 14 years after the start of the decline by which time the population will have decreased to approximately 68 dolphins.

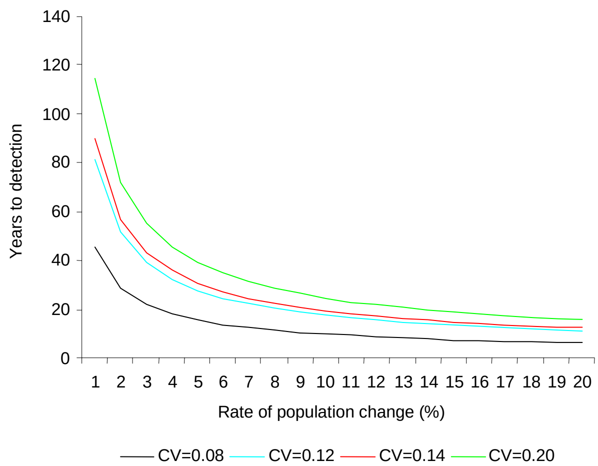

Figure 14. The predicted time to detect different rates of change in the Shannon dolphin population. Four levels of estimate precision are illustrated with values 0.08, 0.12 and 0.14 representing the precision of Shannon population estimates in 2006, 2003 and 1997. Detection probability is set at p=0.05.

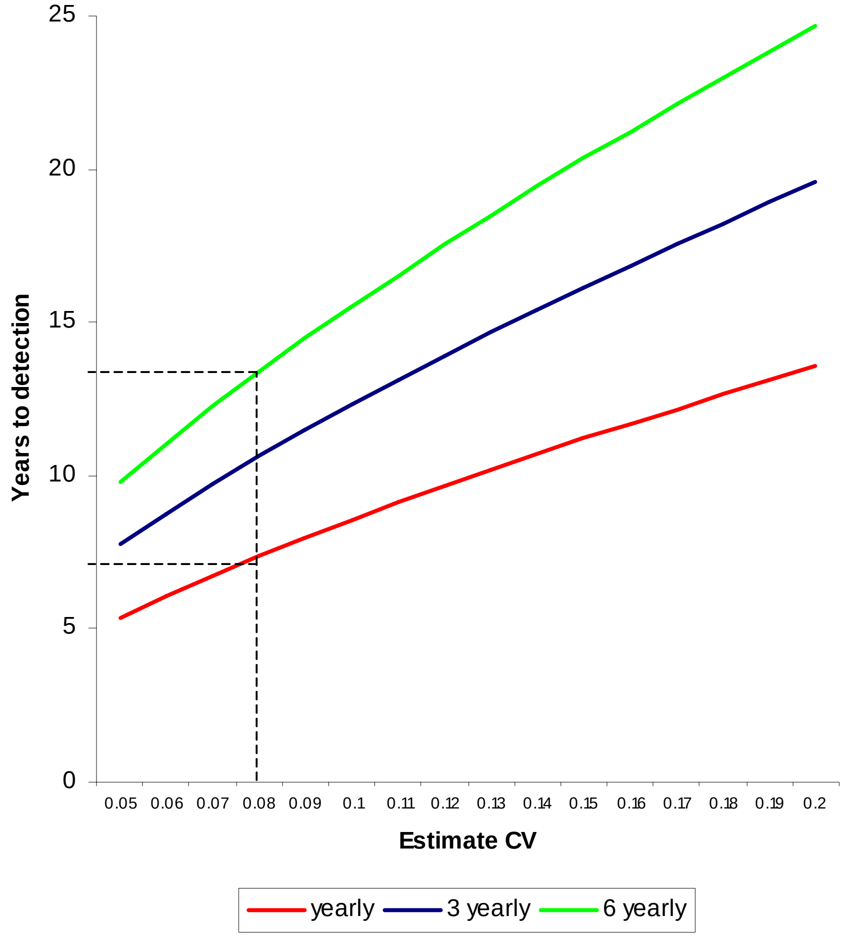

Figure 15. The predicted time to detect an annual rate of change of 5% in the Shannoon dolphin population using three different monitoring periods. The dashed lines show the time to detection with the current estimate precision of cv=0.08 within the three monitoring strategies. Within the current reporting framework a rate of population change of 5% per annum will be detected within the fourth three year reporting cycle (ie 12 years).

Population Viability Analysis (PVA)

The results from VORTEX simulations are summarised below. With the current estimate of population size (140 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 187 ±2 (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 108 ± 2 (SE) after 250 years.

We then ran VORTEX using a starting population size of 76 dolphins equivalent to that predicted after detection of a 5% annual decline using current estimate precision and triennial reporting procedures. Starting with the lower population size of 76 individuals and with no catastrophes, the probability of extinction is 0.036, although with a positive growth rate increasing the mean population size to 100 ±2 (SE) after 250 years. As expected, with one catastrophe, the probability of extinction increases to 0.20 and the mean population size after 250 years is predicted to be 60 ± 2 (SE).

DISCUSSION

Surveys conducted during this study used the same standard survey route followed by UCC dolphin surveys since 1996. Dolphins were encountered throughout the survey area and schools were encountered in 26 of a total of 29 surveys conducted between June 2006 and June 2007. Care was taken to ensure that disturbance effects during data collection were minimised and no excessive reactions to the survey boat were observed during the course of this study. During 80 encounters with dolphin schools over 5,000 photographs yielded 526 identifications of dolphins from their natural marks. These images were graded according to their quality following best practise procedure, minimising rates of false and missed matches. Robust analyses of photo-id data, including mark-recapture abundance estimates, ultimately rely on good quality images and over 40% of photographs taken during this study were high quality grade 1 images. School sizes averaged 6 dolphins, again a similar finding to previous studies in the Shannon (Ingram, 2000; Ingram and Rogan, 2003) with a range from lone animals to schools of over 30 dolphins, typical for this species.

Long term residency and ranging behaviour

Identifications from 2006-7 confirm previous findings that dolphins using the Shannon have a high degree of site fidelity in the Estuary. The degree of marking effects the probability of re-identification and the majority of dolphins only seen within a single month during this study consisted mainly of poorly marked animals. Of 43 permanently marked individuals identified during 2006-7, 22 had been recorded using the Estuary since 1996-7 at the start of dedicated surveys. An analysis of the ranging patterns of these permanently marked dolphins indicated that there was little change in their individual ranging patterns within the Estuary during the last ten years. A degree of habitat partitioning is evident between individuals however. Most dolphins use the critical area at the Estuary mouth but dolphins differ in their up-river ranging limits. A few dolphins have only been seen inside the Estuary east of the Beal Bar (N52º 35.5’, W9º 38.4’). Differences in individual ranging patterns demonstrates the importance of surveying a large area of the outer Estuary; without this degree of coverage many dolphins would be missed by surveys and abundance estimates would be biased downwards.

Seasonal trends in numbers and distribution

Dolphins were seen throughout the year and as with previous years there was a seasonal reduction in the number of dolphins using the Estuary during the winter. Unlike previous years however, relatively high numbers of dolphins were maintained until early November with a marked reduction during January to April (no surveys were possible during December 2006 and May 2007). This seasonal migration out of the Estuary during the winter indicates that the Shannon SAC does not cover the entire range of this population and there is a paucity of data on their movements outside the Estuary (Ingram *et al.,* 2001).

Dolphin schools were distributed throughout the outer Estuary during the winter and the summer months. With sightings data from this study pooled with data since 1996 we used kernel analysis to identify two ‘hotspots’ of dolphin habitat within the Estuary. These hotspots corresponded with critical areas previously identified by Ingram and Rogan (2002) located at the Estuary mouth from the Beal Bar to the Ballybunnion Bank and off Money point. There appeared to be no difference in the distribution of dolphins throughout the year with schools encountered throughout the outer Estuary during the winter. During October and November 2006 most dolphin schools encountered in the outer Estuary were concentrated between the Ballybunnion Buoy (N52º 32.5’, W9º 46.9’) and the Beal Bar (N52º 35.5’, W9º 38.5’).

Calves and neonates

Seven neonatal calves were recorded during this survey all of which were first sighted between August and November 2006. Calves are generally unmarked and can only be reliably identified from their mother. This makes estimation of survival rates very difficult especially with poorly marked breeding females. The number of newly born calves recorded during this study compares closely with previous years, for example 10 neonates were observed during surveys in 2003. As with previous years, calving appears to be concentrated during the late summer-autumn period.

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 November 2006 provided data for a mark-recapture abundance estimate using the programme CAPTURE. There was no indication of migration into or out of the SAC during this sampling period and the majority of marked animals had been sighted during these surveys. We therefore considered the population to be closed during the sampling period. We derived separate estimates from left side and right side identifications and inflated them according to the proportion of marked animals in the population. We then combined these left and right side estimates using inverse variance weighted averaging to give a final estimate of 140 ±12 (SE) dolphins (CV =0.08, 95% CI 125-174) using the lower Estuary during this period. The CV value of 0.08 indicates the high precision of this estimate, which is larger than the previous estimates in 1997 and 2003 (113 ±16 and 121 ±14 respectively). As the 95% confidence intervals of these estimates overlap, we are not able to show a significant increase in the population size. However, there does appear to be an upward trend in the number of dolphins using the Shannon. Without larger scale information on demographic parameters and wide scale ranging patterns it is difficult to interpret this increase, although the signs are that the population appears stable.

Implications of reporting strategy and estimate precision on population management

We examined the power of the current triennial reporting strategy to detect population decline in the Shannon. Using several CV values, the current value of 0.08, two associated with previous estimates, 0.12 and 0.14 (Ingram, 2000; Ingram and Rogan, 2003) and a higher value of 0.2 we predicted the time expected to detect different rates of population decline with estimates derived every three years. The effect of a low CV (<0.1) greatly reduced the time predicted to detect population trends. We also compared the time to detection of population decline (5% annual decrease) between alternative reporting periods of annual, triennial and six-yearly estimates at different levels of estimate precision. Maintaining high levels of precision (CV <0.10) offset the detection delay arising from using longer periods but intervals longer than annual surveys lack sensitivity to detect population decline before serious reductions in the numbers of dolphins occurred. For example, with current three yearly estimates and a current CV value of 0.08 by the time a population decline of 5% per annum was detected (12 years) we predict the population to have declined to 76 individuals compared to a decline to just 98 animals with annual reporting. With a six yearly reporting procedure the population will have decreased by over 50% before the same trend was detected. Levels of precision <0.10 may not be attainable and using a slightly higher CV value of 0.12 achieved in a previous a estimate (Ingram and Rogan, 2003) detection of a 5% annual change will take 15 years using a triennial reporting strategy by which time the population will have reduced to 65 dolphins. Annual reporting will detect this change after nine years by which time the population will have reduced to 88 dolphins. The implications in managing the population to recovery following delays in decline detection are fundamentally important to the probability of survival of this population. Precautionary approaches to management however, where the population is assumed to be declining and managed appropriately would mitigate the effects of this detection lag (Thompson *et al.,* 2000).

Given the importance of estimate CV on effective management we consider estimate precision a priority when designing future reporting strategies. We used data from 2003 surveys to examine the effect of increased survey effort on resulting estimate precision. We ran over 16,000 iterations of capture data using data from 3 to 14 surveys. The results showed little heterogeneity arising through between-survey variability in capture probabilities and an increase in precision with increased survey effort. We used individual sighting frequency and number of surveys as a measure of survey effort. Increased estimate precision (reduced cv values) was directly related to survey effort. Increased effort necessarily means increased survey costs especially if reporting frequency is increased. There is clearly a trade off between monitoring costs and estimate precision and monitoring sensitivity. In our analysis at least 12 surveys with a mean individual capture frequency of ≈ 2 would be necessary to obtain an estimate with a CV value of approximately 0.12. This procedure provides useful information for designing and implementing future monitoring survey strategy.

Population viability analysis

Small populations are more vulnerable to extinction and in order to model the stability of the Shannon dolphin population we used four different scenarios to simulate population viability over a 250 year period. Simulations with VORTEX starting with the estimated current population of 140 dolphins showed that using published data for reproductive parameters the population was unlikely to experience extinction within the 250 year model. Indeed over the 250 year simulated period the modelled mean population size increased to 187 dolphins. We ran further simulations starting with a population size of 76 dolphins, the number of animals expected after detection of a population decline of 5% per annum using current three year reporting cycle and with an estimate CV of 0.08. The mean number of animals was found to recover to 100 animals after 250 years. This situation was rather different when we modelled a single catastrophe, which produced a 25% decline in survival in 1% of years. Both starting populations of 140 and 76 animals showed a population decline over the simulated period indicating that although the modelled population may be stable or increasing over time it may be vulnerable to decline in the event of perturbation through disease or habitat degradation, for example. 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.

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 other disease outbreaks such as morbillivirus in harbour seals, or unusual mortality events, such as the impacts of domoic acid or brevetoxin poisoning as a result of harmful algal blooms. It must be borne in mind 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.

Implications for monitoring strategy

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.

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. 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.

Additional recommended monitoring schemes for the Shannon Estuary

As previously stated (Ingram and Rogan, 2003) we recommend the following:
1. Water quality monitoring for the presence of contaminants;
2. Fish stock surveys in order to monitor the status of dolphin prey resources;
3. Necropsy analysis of stranded animals to determine diet, cause of death and contaminant burden and to provide samples for genetic analyses;
4. Monitoring the growth and activity of the dolphin watching industry;
5. Monitoring of fishing effort and by-catch within the Estuary.

1. Efforts should be made to identify and quantify the present threats to this population 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.

2. 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.

3. Necropsy studies of stranded dolphins found in the Estuary would provide important information regarding, cause of death 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.

4. 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.

5. 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.

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ACKNOWLEDGEMENTS

We would especially like to thank Clodagh Collins, Daphne Roycroft and Laura Walshe for all their hard work and long hours spent in the field. Thanks also to Evelyn Philpott and Barry O'Donaghue for additional assistance in the field and to Alessandro Ponso for assistance in the field and for valuable help with the catalogue sheets for this report. We are also grateful to Simon Berrow for coming to our rescue and lending us a boat battery when our own had gone flat. Thanks also to everyone at Kilrush Marina for accommodating our RIB and in particular to Mick and John for help with various issues during the course of the study. As always, our thanks go to Sue and Geoff Magee for their friendship and support of our work. We would like to thank the National Parks and Wildlife Services for commissioning this work and David Lyons specifically for his support throughout the study.