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Abundance Estimate of Bottlenose Dolphins (*Tursiops truncatus*) in the Lower River Shannon candidate Special Area of Conservation, Ireland

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Abstract

An abundance assessment of bottlenose dolphins (*Tursiops truncatus*) in the Lower River Shannon candidate Special Area of Conservation (cSAC) was undertaken between July and October 2010 using photo-identification. European Union Member States are obliged to designate SACs for bottlenose dolphins to protect important habitats. The Lower River Shannon is the only cSAC in Ireland for this species. A cumulative total of 273 bottlenose dolphins were photographed during the 12 transects, and from these a total of 116 individual animals were identified. They were categorized as follows: 71 with Severity Grade 1 marks, 21 with Severity Grade 2 marks, and 24 with Severity Grade 3 marks. There were 50 dolphins with permanent marks (Severity Grade 1) recorded on both sides of the dorsal fin, 64 on the left hand side only, and 57 on the right hand side only. There was an overlap, with some dolphins occurring in more than one category. Estimates of abundance were calculated using left side, right side, and both side identifications. The proportion of dolphins with re-identifiable marks (Severity Grade 1 only) ranged from 0.60 to 0.63. The estimated abundance of marked individuals was elevated depending on the estimated proportion of marked individuals in the population to give a final estimate of 107 ± 12, CV = 0.12 (95% CI = 83 to 131). Previous abundance estimates for bottlenose dolphins in the Lower River Shannon cSAC ranged from 114 in 2008 to 140 in 2006; the present estimate was within this range and also within the 95% Confidence Intervals for all surveys carried out to date. This suggests that, within the power of the survey technique, the population of bottlenose dolphins in the Lower River Shannon cSAC is relatively stable.

Key Words: bottlenose dolphin, Special Area of Conservation, photo-identification, abundance, mark-recapture

Introduction

Information on the absolute abundance of a population is among the most basic knowledge that can be acquired in conservation ecology (Dawson et al., 2008). Conservation research explores the reasons for such shifts in the size and distribution of animal population changes over time (Evans & Hammond, 2004). Long-term monitoring helps identify trends in cetacean abundance, indicating the status of a population. Under the European Union (EU) Habitats Directive, EU Member States are required to provide strict protection to all cetacean species and their habitats. For two species—harbour porpoises (*Phocoena phocoena* [Linnaeus 1758]) and bottlenose dolphins (*Tursiops truncatus* [Montagu 1821])—this requires the designation of Special Areas of Conservation (SAC). The Shannon Estuary is an important habitat for bottlenose dolphins and is the only candidate Special Area of Conservation (cSAC) (Lower River Shannon, Site Code 2165) for this species in Ireland.

Monitoring spatial and temporal trends in coastal cetacean abundance may employ a wide range of survey techniques, including land, air, and boat-based surveys, as well as the use of telemetry and acoustics. The present study used photo-identification (photo-ID) as a means to generate absolute abundance estimates of bottlenose dolphins in the Shannon Estuary using mark-recapture modelling. Photo-ID is a technique commonly used to study the movements and behaviour of cetaceans worldwide and was first applied to bottlenose dolphins by Würsig & Würsig (1977). This technique works on the principle of photographing individual animals and identifying natural markings unique to that individual (Würsig & Würsig, 1977; Wilson, 1995; Wilson et al., 1999). Photo-ID has also been used to study a wide range of marine mammals, including other dolphin species, baleen whales (Hammond, 1986), and seals (Hiby et al., 2007), as well as terrestrial animals. In addition to abundance, the technique is used to estimate movements, population parameters, and behavioural ecology (Wood, 1998; Wilson et al., 1999; Grellier et al., 2003; Weir et al., 2008; Hart et al., 2010).

Studies in the Shannon Estuary using photo-ID have been carried out since 1993 and have shown that the bottlenose dolphins in the estuary are resident and occur throughout the year (Berrow et al., 1996; Ingram, 2000). Historical references suggest the dolphins have been in the estuary since at least 1835 (Knott, 1997) and probably much longer. A recent genetic study of bottlenose dolphins in Ireland suggests that the bottlenose dolphins in the Shannon Estuary may be genetically discrete and thus of very high conservation value (Mirimin et al., 2011).

Several unreviewed population assessments of bottlenose dolphins in the Lower River Shannon cSAC have been carried out since 1997 (Ingram, 2000; Ingram & Rogan, 2003; Englund et al., 2007) with the most recent in 2008 (Englund et al., 2008). To fulfill the requirements for monitoring established within the EU Habitats Directive, a population assessment was undertaken between July and October 2010 using mark-recapture photo-ID of individual dolphins.

Materials and Methods

Dedicated line transects were carried out on fixed, predetermined routes in the Shannon Estuary (Figure 1) from a 6-m XS Rigid Inflatable Boat. The route was consistent with those described as "long" in Berrow et al. (1996) and "full" by Ingram (2000). On one occasion, the route was broken as bottlenose dolphins were observed in the distance; and on two occasions, the transects included extra survey effort to the west at the boundary of the cSAC. The vessel returned to the position before the route was broken each time. Three observers were used for each survey: the coxswain in the middle of the vessel surveyed ahead of the vessel, with one observer scanning 90° to port and the other 90° to starboard. Transects were only carried out in Beaufort Sea State 2 or less and at a maximum velocity of 20 km hr^{-1}. Each transect was started at different times (from 0600 to 1000 h) to take advantage of suitable weather windows which did not always last a full day. Each transect took around 5 to 8 h depending on the number of dolphins encountered. The route of the survey vessel and position of dolphin schools encountered was recorded on a handheld Garmin 72 GPS, and tracks and waypoints were downloaded

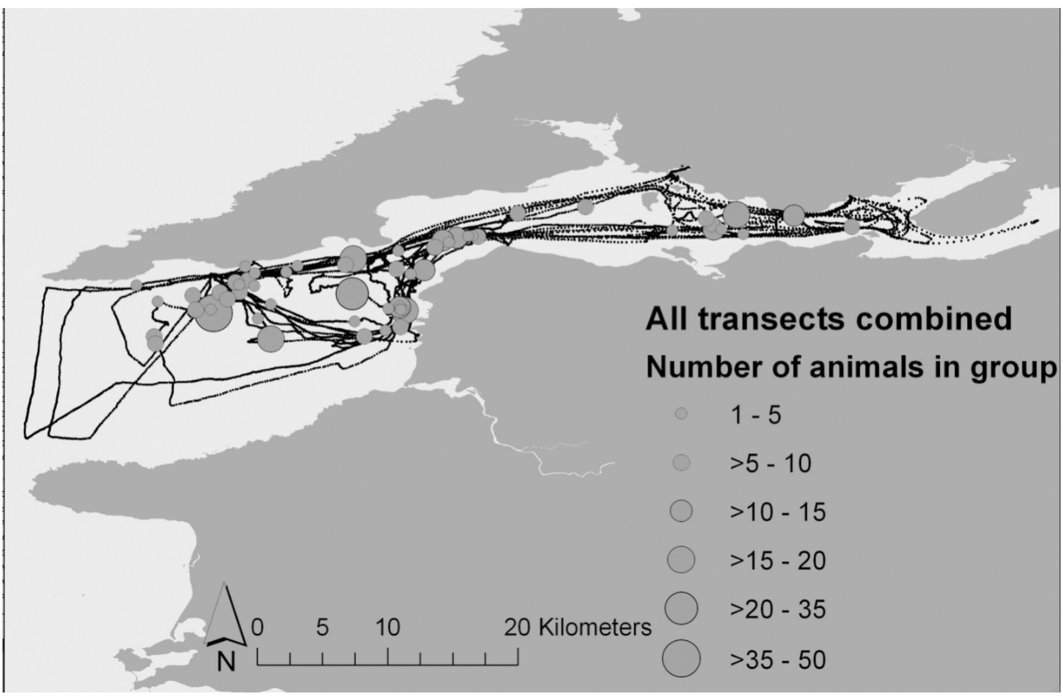

Figure 1. Survey track lines and location of all dolphin sightings recorded during the abundance estimate of bottlenose dolphins in the Lower River Shannon cSAC in 2010

using Garmin *MapSource*® software. Three transects were carried out each month from July to October 2010; thus, a total of 12 transects were carried out during this survey.

Data Collection

All bottlenose dolphin schools, defined as all dolphins within 100 m radius of each other (Irvine et al., 1981), were recorded along with time, latitude, and longitude at the start and end of each group encounter. Each group was approached slowly, and group size was recorded as the total number of individuals present. The total number of adults, juveniles (subadults), and calves within each group were recorded. A juvenile was defined as approximately two-thirds the size of an adult (Ingram, 2000) and generally more pale than adults. Calves were defined as smaller than juveniles and as < 1 y old. Neonates were determined from the presence of neonatal folds following Ingram (2000). An attempt was made to photograph the left and right sides of all dolphins' dorsal fins in each school. Photo collection continued until it was thought all individuals in the group had been photographed or the group avoided the survey vessel.

Photo-Identification

A minimum of two high-quality Canon EOS D20 digital cameras, one with a Canon 70-200 mm f2.8USM lens and Canon 2x converter and one with a Canon f3.0 300 mm lens were used to acquire images. All dolphin images were sorted and graded from 1 to 3 following criteria published by Ingram (2000):

- *Photo Grade 1* – Well-lit and focused shots taken perpendicular to the dorsal fin at close range
- *Photo Grade 2* – More distant, less well-lit, or slightly angled shots of dorsal fins
- *Photo Grade 3* – Poorly lit or out of focus shots taken at acute angles to the dorsal fin

For each encounter, images of dorsal fins were recorded as being of the "left side" or "right side" or if both sides of the individual dolphin's dorsal fin was photographed then "both sides" for each encounter. The extent of natural marks on identified dolphins was also graded following definitions in Ingram (2000):

- *Severity Grade 1* – Marks consisting of significant fin damage or deep scarring that were considered permanent
- *Severity Grade 2* – Marks consisting of deep tooth rakes and lesions with only minor cuts present
- *Severity Grade 3* – Marks consisting of superficial rakes and lesions

A catalogue of dorsal fins was established for this project and cross-referenced with a catalogue of individual dolphins recorded in the Shannon Estuary by the Shannon Dolphin and Wildlife Foundation (see www.shannondolphins.ie). This catalogue contains images of around 200 individually identified dolphins, some recorded in the estuary since May 1993. All images were scored for quality, but only good quality images were used in the final analysis to reduce error in matching images. Each file was stored as a jpeg with a file size of 2 to 3 MB. Two observers were used to identify and match all individuals following the recommendations of Stevick et al. (2001).

Deriving an Abundance Estimate

Validated datasets of all sightings/resightings of individual dolphins for Photo Grades 1 through 3 and Severity Grade 1 were used in the mark-recapture analysis. These datasets were incorporated into a closed model incorporating heterogeneity in capture probability (Chao M(th)) (Chao et al., 1992) using the software programs *MARK* and *CAPTURE* (Version 5.1, Build 2600). Multiple sample capture-recapture abundance estimates of closed populations depend on the assumptions that

i. the population is closed during sampling period,
ii. animals do not lose their identifying marks during sampling period,
iii. all marks are correctly recorded in each capture,
iv. each animal has an equal and constant probability of being captured. (Ingram, 2000, p. 40)

It was possible either to constrain one or more parameters or to set the model to estimate all parameters. The *MARK* program then ranked the likelihood of each model on the basis of best fit, using the Akaike Information Criterion (AIC) value (Akaike, 1974). The key parameters of the model are S (probability of survival), gamma" (probability of emigration), gamma' (probability of an emigrated animal staying outside the study area), and N (population size within the study area). Together, these were used to obtain overall population size estimates, utilizing a biased corrected estimate using the delta method recommended by Wilson et al. (1999) after taking account of the (weighted) mean proportion of well-marked animals and some measure of survival/migration obtained from the model.

Results

All 12 transects were carried out in full between 5 July and 21 October 2010 in favourable weather

Table 1. Date, sea state, group details, and proportion of photographed individuals identified during the abundance estimate in the Lower River Shannon cSAC

Transect number	Date	Sea state	No. groups	No. individuals[1]	Mean group size ± SE (range)	No. of individuals photographed[2]	% dolphins identified in group
1	9 July	2	1	12	12	12	100
2	12 July	0-1	11	78	7.0 ± 0.9 (3-13)	34	43
3	23 July	1-2	8	43	5.4 ± 2.0 (2-19)	22	51
4	2 August	0-1	5	35	7.0 ± 2.2 (2-13)	17	48
5	14 August	1-2	4	29	7.3 ± 1.3 (4-10)	12	41
6	15 August	1	10	59	5.9 ± 1.3 (1-15)	26	44
7	6 September	0-2	4	36	9.0 ± 3.8 (4-20)	18	50
8	12 September	2	3	17	5.7 ± 1.5 (3-8)	11	65
9	25 September	1	4	59	14.8 ± 11.8 (1-50)	27	45
10	14 October	1-2	6	81	13.5 ± 4.45 (6-35)	37	46
11	16 October	0-1	4	49	11.8 ± 4.1 (4-23)	32	65
12	21 October	2	4	49	12.3 ± 4.5 (4-20)	25	51
Total			**64**	**547**		**273**	

[1] Estimated visually
[2] Estimated from photo-ID catalogue

conditions (Table 1). Bottlenose dolphins were located on each transect. If the same group was encountered twice on the same survey (e.g., during a course west and then on the way back while traveling east), they were treated as only one group. Dolphins were located throughout the transect, but concentrations of sightings occurred off the Moneypoint power station in the mid-estuary, off Kilcredaun Head and Leck Point at the entrance to the estuary, and off Kilcloher Head in the outer part of the Lower River Shannon cSAC (Figure 1).

A total of 64 dolphin groups were encountered with a total of 547 individuals recorded (Table 1). The overall mean group size (± SD) was 8.5 ± 1.0 with a median of 6.0 (range 4 to 12.5). Group size ranged from 1 to 50 individuals overall. Lone dolphins were reported on two occasions. Although there appeared to be a trend towards increased group size from July-August to September-October, this was not significant (ANOVA, F = 0.93, df = 10, $p = 0.52$). There was no significant difference in the mean (Kruskall-Wallis H = 4.86, df = 5, $p = 0.43$) or median (Kruskall-Wallis H = 3.71, df = 4, $p = 0.45$) group size if early transects (July-August) were compared to late transects (September-October).

Photo-Identification

A total of 273 bottlenose dolphins were photographed during the 12 transects (Table 1). The number of individual dolphins identified in each group is compared to the estimated group size. The proportion of dolphins identified on each transect ranged from 41 to 100% with a mean of 54%, the difference being those marked dolphins not photographed or not identifiable due to a lack of distinctive notches and marks. The discovery curve of Severity Grade 1 new dolphins (Figure 2) has not reached a plateau, suggesting we have not yet captured all the dolphins in the estuary. There were 13 new individuals, recorded on Transect 9 (25 September) in a large group off Kilcloher Head that had not previously been recorded during the present survey. This created a step on the discovery curve (Figure 2). Of these 13 individuals, nine had been recorded previously in the Lower River Shannon cSAC during previous surveys, which suggests these individuals had not been encountered or photographed before during this survey rather than reflecting immigration into the survey area.

A total of 175 dolphins were photographed from the left, 169 from the right, and 97 from both sides of their dorsal fin. Of these, 71 were categorised with Severity Grade 1 marks, 21 with Severity Grade 2 marks, and 24 with Severity Grade 3 marks, resulting in 116 identifiable individuals in total. Only 27 dolphins photographed could not be allocated to one of the three grades as the images were too poor. This included 17 dolphins photographed from the left side and 13 from the right; some individual dolphins were photographed from both sides.

The results of the photo-ID are presented as dolphins identified by permanent (Severity Grade 1), temporary (Severity Grade 2), and superficial (Severity Grade 3) marks on the left side of the dorsal fin, the right side, and from both sides (Table 2). Thus, there were 50 dolphins with Severity Grade 1 marks recorded on both sides of the fin, 64 with Severity Grade 1 marks on the left hand side, and 57 with Severity Grade 1 marks on the right hand side. These were the most robust datasets available for mark-recapture analysis. A total of 51 dolphins

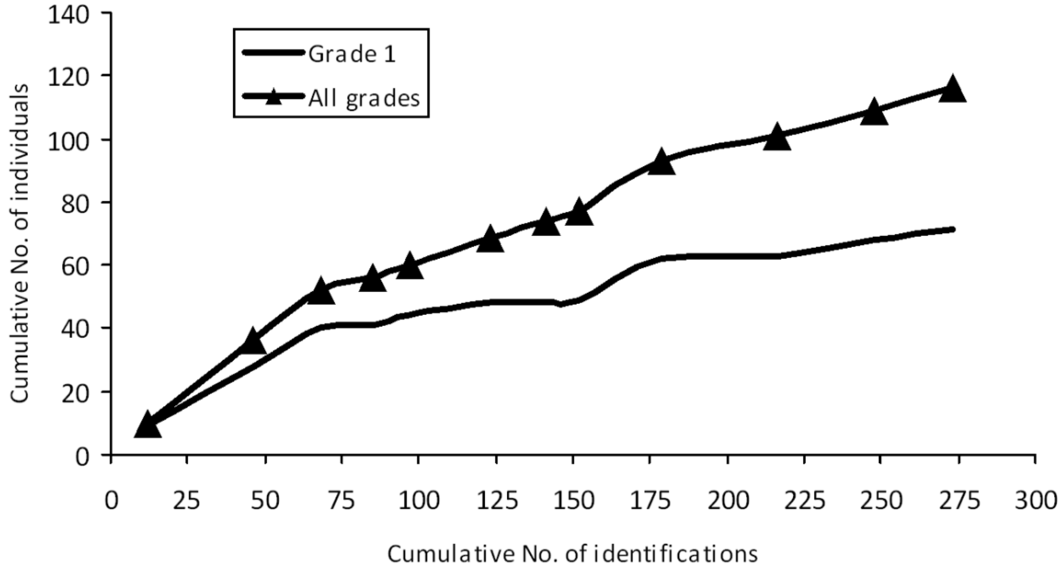

Figure 2. Discovery curve of all marked (all grades) and well-marked (Severity Grade 1) bottlenose dolphins recorded in the Lower River Shannon cSAC during 2010

Table 2. Abundance estimates of marked bottlenose dolphins identified from Severity Grade 1 marks on the left side and right side of the dorsal fin and on both sides via *CAPTURE* model from Photo Grades 1 through 3 (*n* = number of animals captured for estimate)

Photo quality	Dorsal fin	AIC	*n*	Nhat	Standard error	95% CI
Grade 1	Both	161.90	41	55	6.7	47-75
	Left	148.82	50	77	12.9	61-115
	Right	146.24	45	62	7.6	53-84
Grade 1+2	Both	372.18	52	59	4.2	59-72
	Left	358.13	61	79	8.3	69-103
	Right	374.62	57	67	5.5	61-84
Grade 1+2+3	Both	393.52	52	56	3.35	53-67
	Left	385.16	64	85	9.0	74-111
	Right	405.77	57	65	4.6	60-79

with temporary marks or superficial marks were rejected from the dataset if only Severity Grade 1 marks were used. This filtering reduced the probability of false negatives (i.e., bottlenose dolphins were present but not recaptured) or animals losing their marks during the study period.

Abundance Estimates

Estimates of abundance were calculated using left side, right side, and both side identifications. Only bottlenose dolphins with Severity Grade 1 marks were used, which provided the most robust dataset. We found the *CAPTURE* model M(th) for a closed population incorporating capture probability heterogeneity (Chao et al., 1992) provided the best fit (i.e., lowest AIC value) compared to other relevant models available on *CAPTURE*. The estimated total number of marked individuals in the population (Nhat) was calculated by the model. We calculated estimates using dolphins recaptured from the left side of the dorsal fin (Left), dolphins recaptured from the right side of the dorsal fin (Right), and dolphins recaptured from both sides of the dorsal fin (Both). We also calculated estimates using Photo Grade 1, Photo Grade 1+2, and Photo Grade 1+2+3 images to explore the effect of photo quality of estimates (Table 2).

CAPTURE derives confidence intervals under the assumption that the number of individuals not captured in the population is log normally distributed, resulting in the upper estimate being larger than if assumed to be normally distributed. The estimates of the marked population varied depending on which set of dorsal fin images were used.

The lowest AIC was consistently reported for estimates using the left side (i.e., Photo Grade 1, AIC Left > AIC Right; Table 2), which was due to the greater sample size used in this estimate. There were very few differences associated with photo quality (Table 2). Thus, in order to minimize violations of the assumption that all marks were correctly recorded and those animals do not lose their identifying mark, we selected only Photo Grade 1 images. Abundance was therefore estimated using the most robust dataset of Photo Grade 1 images of Severity Grade 1 fins. The estimated population of the subset of marked individuals ranged from 55 to 77, depending on which fin side was used.

The proportion of dolphins with Severity Grade 1 identifiable marks is shown in Table 3. This ranged from 0.60 to 0.63 depending on which side of the dorsal fin was used. The variance of each estimate was calculated using the delta method recommended by Wilson et al. (1999) where:

$$\text{Var } N = N^2 (\text{varNhat}/\text{Nhat}^2 + 1- \theta/n\theta)$$

Where: N = estimated total population size

Nhat = estimate of the subset of marked individuals

θ = estimated proportion of animals with Severity Grade 1 marks in the population

var = SE^2

The estimated abundance of marked individuals is increased according to the estimated proportion of marked individuals in the population (Table 4). An estimate of 0.60 was used for estimates using both sides of the dorsal fin. Thus, the population estimate varied from 90 ± 12, CV = 0.13 (95% CI = 66 to 113) for both sides to 128 ± 24, CV = 0.19 (95% CI = 81 to 174) for left only.

The data from the left side and right side were combined as an inverse variance weighted average, assuming independence following the recommendations described by Wilson et al. (1999). Data from the combined (right, left, and both) average uses the data in right and left twice in the weighted average (once each and then both in "both"); thus, we have excluded this from the calculation. These two values were combined to give a final estimate of 107 ± 12, CV = 0.12 (95% CI = 83 to 131), which was the lowest estimate recorded to date.

Discussion

This is the fifth dedicated study using mark-recapture to estimate the abundance of bottlenose dolphins in the Lower River Shannon cSAC. The present survey was carried out in very favourable conditions, which resulted in a large number of groups (n = 64) being recorded. The encounter rate per transect in the present study (mean 5.3 groups per transect) was higher than reported by Englund et al. (2007, 2008) but similar to Ingram & Rogan (2003). This may be due in part to the definition of a group. We kept closely to the definition of 100 m as the minimum distance between groups which, although consistent with previous studies, can be hard to implement clearly as groups were highly mobile and individuals or subgroups regularly deviated from the main group. Bottlenose dolphins in the Lower River Shannon cSAC have been shown to demonstrate classic fission-fusion social structure, with individuals mixing throughout the population (Foley et al., 2010). Thus, the concept of a group, outside adult-calf pairings, is an artificial construct, and associations between individuals may be comparatively weak. Still, the median group size in this study was 6.0, which was similar to that reported previously.

Table 3. The proportion of bottlenose dolphins with identifiable marks (Mark Severity Grade 1 only)

Side	Long-lasting marks Number with	Number without	Total	Proportion (θ)
Left	64	42	106	0.60
Right	57	34	91	0.63

Table 4. Abundance estimates of the number of marked individuals in the lower River Shannon cSAC using images of the left, right, and both sides of the dorsal fin (Mark Severity Grade 1 only)

Side	Nhat	Proportion of animals with marks (θ)	Abundance estimate	SE	Coefficient of variation	Standard error 95% CI
Both	55	0.60	89.55	12.02	0.13	66-113
Left	77	0.60	127.53	23.60	0.19	81-174
Right	62	0.63	98.98	14.54	0.15	70-127

Abundance estimates using mark-recapture work on a number of assumptions such as the population being closed during the sampling period, animals not losing their markings over the duration, and that all animals have an equal chance of being "captured" during each encounter. If an abundance survey is carried out over durations of many months or even years, it is highly unlikely that these populations remain closed or that each animal has the same probability of encounter. Well-marked individuals can be identified more regularly than lesser marked individuals, while some have no marks at all. The proportion of unmarked animals must be estimated in order to transform the data to account for these individuals within an estimate. Failure to do so will lead to an underestimation of the population size. As the present study was carried out over a period of 4 mo, the probability of violating the assumption of a closed population is minimized and no immigration or emigration was expected.

Population estimates of bottlenose dolphins in the Lower River Shannon cSAC have ranged from 140 (95% CI = 125 to 174) by Englund et al. (2007) to 107 (95% CI = 83 to 131) in the present study, which was the lowest estimate recorded to date. Abundance estimates of 113 were recorded in 1997 by Ingram (2000), 121 in 2003 by Ingram & Rogan (2003), and 114 in 2008 by Englund et al. (2008). One possible reason behind the variability is that we did not capture all the dolphins in the population during the present survey. This possibility is supported by the discover curve of new individuals which had not yet plateaued. The proportion of dolphins identified from those observed during each transect ranged from 41 to 100%, with a mean of 54% (Table 1), which does suggest that not all identifiable animals in each group were captured (photographed). However, the overall proportion of marked individuals in the present study varied from 0.60 to 0.63, which was consistent with previous studies, suggesting this was not a major source of variability between studies.

Similar studies of resident bottlenose dolphins in the UK have produced estimates of the same magnitude. In the first abundance estimate produced for bottlenose dolphins in the UK using mark-recapture analysis, Wilson et al. (1999) estimated 129 dolphins (95% CI = 110 to 174) occurred in the Moray Firth, Scotland, during their summer sampling period. In 2003 and 2004, Culloch (2004) estimated an abundance of 108 (95% CI = 99 to 117) and 61 (95% CI = 50 to 72) bottlenose dolphins, respectively, at the same site and season. There is evidence that bottlenose dolphins in the Moray Firth are becoming less abundant following range expansion (Wilson et al., 2004). In Cardigan Bay, Wales, another site with resident bottlenose dolphins in the UK, abundance estimates over the period 1989 to 1998 ranged

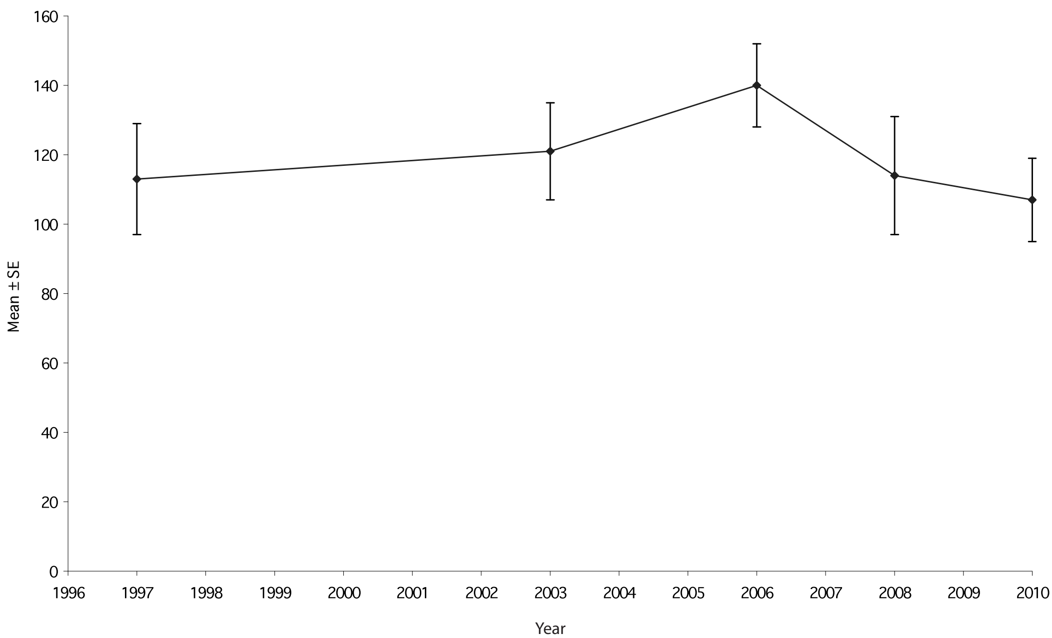

Figure 3. Trend in bottlenose dolphin abundance estimates (mean ± SE) in the Lower River Shannon cSAC from 1997 through 2010

from 158 to 235; and since 2001, from 145 to 227 with an apparent increase in recent years (Posada, 2006). It is remarkable how similar these estimates are compared to the Shannon Estuary when you consider each site is different in terms of size, bathymetry, and presumably productivity.

The abundance estimate in this study was the lowest estimate recorded to date in the Lower River Shannon cSAC. Englund et al. (2007) suggested that the estimate of 140 ± 12 reported in 2006 indicated an upward trend in the abundance of bottlenose dolphins; however, a subsequent study (Englund et al., 2008) did not support this, and they attributed the lower estimate in 2008 to a lower sampling effort rather than a reflection of a true decline in abundance. If we ignore the 2006 estimate, which was considered elevated compared to other studies, all estimates are actually within 6 to 14 individuals or 5.3 to 11.5% of each other, which is remarkably consistent. The present estimate was within the range of 95% CI for all surveys carried out to date (Figure 3). This suggests that, within the power of the survey technique, the population of bottlenose dolphins within the Lower River Shannon cSAC is relatively stable. However, the population is relatively small, and recent genetic studies suggest it is genetically discrete (Mirimin et al., 2011) and, thus, vulnerable to any increase in mortality, especially of adult animals. Ongoing population monitoring is essential to ensure that any change in abundance is recorded within reasonable time-scales to facilitate active management if appropriate.

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