Bottlenose dolphins in the Lower River Shannon SAC, 2022

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Executive Summary

Dedicated boat-based transects were carried out in the Lower River Shannon SAC (Side Code 002165) over twelve days on fixed, pre-determined routes between June and September 2022.

A total of 657 nmls of survey effort was carried out with a mean of 54.8 nmls per transect and a duration of 417 minutes. Surveys were carried out in good (95% ≤ seastate 2) sea conditions. Bottlenose dolphins were encountered on all 12 transects with a total of 44 sightings and a mean of 3.7±1.4 groups per transect. From these individual dolphins were captured on 316 occasions at a mean of 26.3±7.7 per transect. From the total of 316 captures a catalogue of 106 unique dolphins was created. From these 61 individuals presented with grade 1 markings, 36 individuals and only 9 individuals with grade 3 fins. Both sides of the dorsal fin were photographed on most dolphins (86.8%; 92 individuals) with only 6 (5.6%) photographed only from the left side and 8 (7.5%) only from the right side.

Maturity was determined for 105 individual, of which 79 (75.2%) were considered adults, 14 (13.3%) juveniles with five calves and seven neonates. Two calves with Severity Grade 3 fins and all neonates were not included in the mark-recapture modelling. Discovery curves of the number of new dolphins recorded as the total number of individually recognisable dolphins photographed were beginning to plateau out, suggesting not quite all the dolphins in the population had been captured.

Capture histories from between 53 and 97 individual dolphins were used to estimate abundance depending on the model used. Of these 61 (62%) were of Severity Grade 1 and photographed from both sides of the dorsal fin and 36 (37%) were of Severity Grade 2. A total of six dolphins with Grade 1 or Grade 2 fins were only photographed from the left side and eight from the right. Using images with Severity Grade 1+2 fins provided the most robust dataset and minimised violations of the assumption that all marks were correctly recorded and those animals did not lose their identifying marks.

Estimates of Nhat, which is the estimated total number of marked individuals in the population, ranged from 0.57-63 for Grade 1 fins depending on whether they had been photographed from the Left, Right or from Both sides. When including Grade 2 fins in the models this increased to 0.91-0.98. The abundance estimate varied from 112 ± 9, CV = 0.11 (95% CI =89-135) for both sides using only Grade 1 fins to 107 ± 7, CV = 0.07 (95% CI =93-121) for both sides of both Grade 1+2 fins combined.

Data from Severity Grade 1 fins from the left side and right side were combined as an inverse variance weighted average. These two values were combined to give a final best estimate of **116 ± 9** with a **CV 0.08** and **95% Confidence Intervals of 103 to 122**.

The CV of the estimate in the current study was lower (0.08) than most previous estimates showing the estimate was robust. When compared to the only other estimate with the same precision (CV=0.08: 2006-2007) then the population has decline by 17.6% during the last 16 years. However, the overall estimate from 2022 was consistent with previous abundance estimates from the Lower River Shannon SAC suggesting the population is stable, within the power of the monitoring strategy to detect change.

1 Introduction

The Shannon Estuary is one of the most important habitats for bottlenose dolphins (*Tursiops truncatus*) in Ireland. The population is genetically discrete, numbers around 140 individuals, is an important calving area and individuals are largely restricted to the Shannon Estuary and adjacent waters (Ingram 2000; Mirimin *et al*., 2011; Baker *et al.,* 2018a). Research on this population has been ongoing since 1993 (Berrow *et al.,* 1996; Ingram 2000) making it the best studied cetacean populations in Ireland and one of the best studied dolphin populations in Europe.

Although both harbour porpoise (*Phocoena phocoena*) and common dolphin (*Delphinus delphis*) have very occasionally been recorded in the mid-estuary, east of Scattery Island (O'Callaghan *et al*., 2021) and minke whales (*Balaenoptera acutorostrata*) in the outer estuary, bottlenose dolphins are the only cetacean species to be regularly, and frequently, recorded within the Shannon Estuary. Highest encounter rates are off Beal Bar and Kilcredaun Head in the outer Estuary, and off Moneypoint and Tarbert Power stations in the middle section of the estuary (Ingram and Rogan 2002). The Shannon Estuary was designated as a Special Area of Conservation, with bottlenose dolphins as one of the qualifying interests, in 2000.

Within the Shannon Estuary most dedicated dolphin surveys have been carried out in the mid and outer part of the estuary during summer months. Much less is known about how dolphins use the inner estuary or abundance and movement patterns during winter months. Englund *et al.* (2007) carried out dedicated surveys of the mid and outer estuary through the summer and winter which led to one of the highest abundance estimate (140±12) reported to date. Berrow (2009) showed dolphins occurred frequently upriver in the inner estuary during winter, with encounter rates as high as that during summer months. Interestingly results from static acoustic monitoring of four sites from Moneypoint Power Station upriver to Shannon Airport (Carmen *et al.,* 2021) showed that dolphins were detected upriver more frequently than expected with detections off Foynes Island on 39% of days, Aughinish Alumina on 20% of days and on as much as 16% of days at Shannon Airport. When foraging clicks were explored between 12% and 22% were classified as foraging at Foynes, Aughinish and Shannon Airport, which is considerably higher than Moneypoint (7% foraging) which suggests dolphins regularly travel upriver to forage (Carmen *et al.,* 2021).

The Shannon dolphin population exhibits population structure which can be crudely described as comprised of "inner" and "outer" estuary dolphins. All individuals who have been sighted in the inner estuary have also been sighted in the outer estuary, suggesting the population mixes in this area. But many of the "outer" estuary dolphins have not been recorded in the inner estuary (Baker *et al.* 2018a). Around 25% of the known population use the inner estuary all the time which has strong management implications as the degree of exposure to anthropogenic threats would be different for individuals of the inner and outer areas.

Bottlenose dolphins were thought to be largely restricted to the Shannon Estuary, but recent evidence suggests there are using Tralee and Brandon Bays to the west of the mouth of the estuary more than had been previously reported (Levesque *et al.* 2016). Some dolphins recorded in Brandon Bay in recent years have not been seen back in the estuary suggesting a "permanent emigration" may have occurred (Ludwig *et al.,* 2021). Brandon Bay has been shown to provide good foraging area for bottlenose dolphins (Charish *et al.,* 2021).

1.1 Abundance estimates of Shannon dolphins

Estimating dolphin abundance can be challenging due to their high mobility and defining what is a population (Hammond *et al*., 2021). In the Shannon estuary, a minimum abundance estimate of 56-68 individuals recorded in October 1994 was presented in Berrow *et al.* (1996) following a simple technique described by Hammond and Thompson (1991) involving simultaneous land-based observations.

Ingram (2000) repeated this technique in 1996, 1997 and 1998 and reported minimum estimates of between 10 and 30 individuals during each survey

The first robust abundance estimate of dolphins using mark-recapture modelling of photo-id data was carried out in 1997 by Ingram (2000). At least two surveys were carried out each month between April and September and one per month during winter (weather permitting). During 45 photo-identification boat surveys Ingram (2000) identified 53 individual dolphins with well-marked dorsal fins. This resulted in an estimate of 113±16 dolphins with a CV of 0.14 and 95% Confidence Intervals of 94-161 individuals.

Since this first study a number of abundance estimates have been carried out using mark-recapture modelling of photo-id data. These estimates ranged from a peak of 140±12 in 2006 to a minimum of 107±12 in 2010 but were quite consistent over the period 1997-2018 (Ingram 2000; Ingram and Rogan 2003; Englund *et al.*, 2007; 2008; Berrow *et al.*, 2010; Rogan *et al.*, 2015: 2018). During an extensive period of photo-id in the Shannon Estuary between 2012 and 2015 (Baker *et al.*, 2018a), a discovery curve of individuals identified against the cumulative number of identifications reached a clear plateau suggesting all individuals present in the estuary were captured. No new adults or juveniles were recorded during the 2015 field season (excluding additions of new born calves to the population) resulting in an estimated extant population of 145 individuals comprising 80 adults, 25 juveniles and 40 calves (Baker *et al.*, 2018a). Excluding dependent calves, 121 individuals were sighted, of whom 98% (*n* = 119) were sighted in multiple years (Baker *et al.*, 2018a). Concurrent with this four year study, in 2015 Rogan *et al.* (2015) estimated an abundance of 114±14 with 95% Confidence Intervals of 90-143, which fitted within the estimate by Baker *et al.* (2018a).

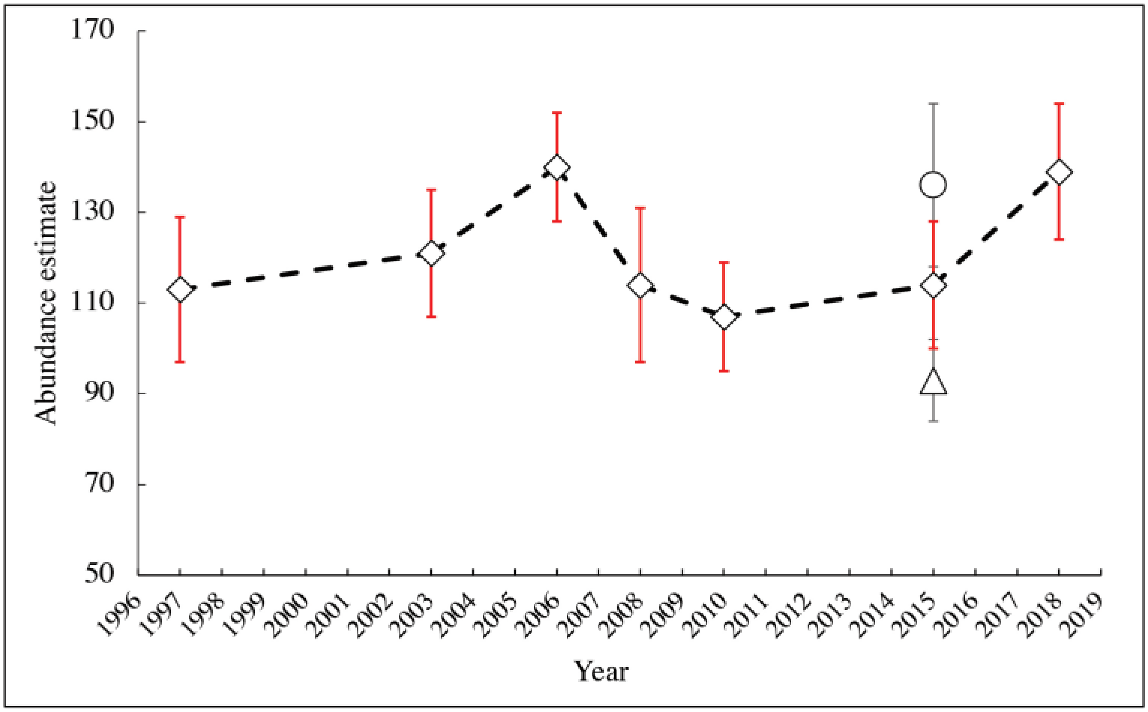


Figure 1. Mark-recapture abundance estimates (mean ± SE) of bottlenose dolphins in the Lower River Shannon Estuary SAC from 1997 to 2018, including those presented in Blásquez *et al.* (2021). IWDG 2015 (circle) and revised NPWS 2015 (triangle). From Blásquez *et al.* (2021).

As part of a population viability study, Blásquez *et al.* (2021) found a number of false positives in Rogan *et al.* (2015) dataset and provided a revised estimate of 93 ± 8.81 with a CV of 0.09 and 95% Confidence Intervals of 83-103, which would be the lowest abundance estimate published to date. A mark-recapture analysis was also carried out by Blásquez *et al.* (2021) on the IWDG photo-identification catalogue during the same time period, and an estimate of 136 ± 18.0, with a CV of 0.13 Confidence Intervals of

125-202 was calculated. Interestingly, the most recent abundance estimate from the Shannon Estuary in 2018 (Rogan *et al.*, 2018) produced a very similar abundance (139 ± 15.23; CV = 0.11; 95% CI = 121 to 160) to that calculated using the IWDG photo-identification catalogue in 2015 (Blásquez *et al.*, 2021). Since the first mark-recapture estimate in 1997, estimates have been largely consistent, suggesting the population is stable. However, a population viability analysis which was carried out on the latest data from the Shannon Estuary suggested that the dolphin population is vulnerable to even small increases in adult mortality, or a reduction in reproduction rates (Blásquez *et al.*, 2021).

1.1 Lower River Shannon SAC

The Lower River Shannon SAC (Side Code 002998) was designated in 2013 with bottlenose dolphins as the sole qualifying interest.

The aims of the current survey were:

i) to undertake a series of boat-based surveys of bottlenose dolphin in the Lower River Shannon SAC;

ii) to design practical and repeatable survey routes in both the Northern and Southern components of the Lower River Shannon SAC;

iii) to derive a robust and precise population estimate for bottlenose dolphins in the SAC using mark-recapture photo-identification based sampling;

iv) to determine the associated Coefficient of Variation (CV) and 95% Confidence Intervals about the estimate and

v) to examine site faithfulness for bottlenose dolphins in the Lower River Shannon SAC.

2 Methods

2.1. Survey area and Platform

Dedicated line transect surveys were carried out on fixed, pre-determined routes in the Lower River Shannon SAC. The route was consistent with all previous surveys carried out within the SAC. The survey vessel travelled between 10-12kts to ensure coverage of the survey sites could be completed within a day. Transects were only carried out in sea-state ≤3 with good visibility (>6km) and low swell (<1m). Three surveys were carried out each month from June to September 2022.

2.1.1 Boat platform used

The IWDGs' own 6m XS Rigid Inflatable Boat (RIB) was used as the survey vessel. The vessel known as *Muc Mhara* is powered by a 115 hp 4 stroke Yamaha engine with a 2.5 hp Mercury auxiliary for safety considerations. The vessel has two boat-mounted GPS receivers and plotters and a depth sounder for safe navigation. The route of the survey vessel and waypoints were acquired using two independent Garmin 72 hand-held GPS (one for back-up). Start and end of survey, changes in environmental conditions and the position of the start and end of dolphin schools encountered were logged with unique waypoints which included location and time (UTC). Map files from each survey are downloaded using Garmin MapSource® software and saved as a text file. These data were then used to create ArcView (Version 9) shape files of the survey track and location of all sightings recorded during each survey.

IWDG RIB *Muc Mhara*

2.1.2 Survey route

The pre-determined survey route is shown in Figure 2 and was consistent with all previous NPWS surveys. The route was first used by Berrow *et al.* (1996) and was determined from fixed marks in the estuary (navigation buoys), as these surveys were carried out prior to the availability of GPS systems on recreational and non-military vessels. The current route only covers the mid and northern sections of the outer estuary and none of the inner estuary, east of Tarbert , Co. Kerry. The survey design was based on historical precedence and has provided a long time-series of survey data spanning 25 years. However it should be noted that this survey design only covers less than half of the known range of bottlenose dolphins within the Lower River Shannon SAC.

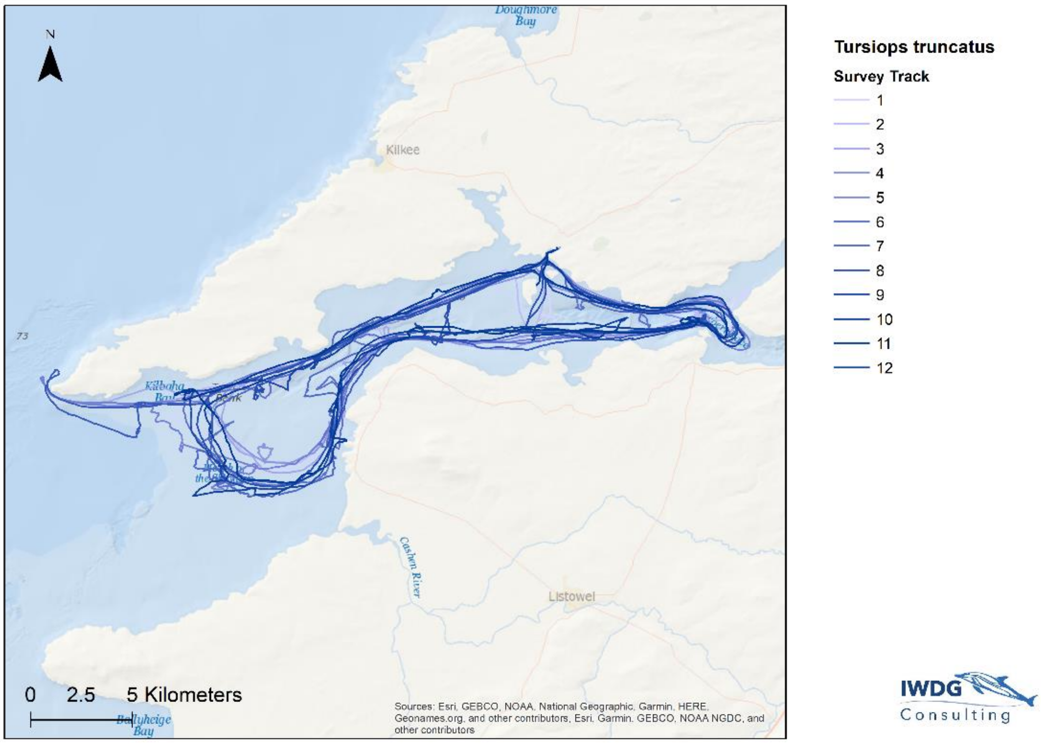


Figure 2 Pre-determined survey routes of the Lower River Shannon SAC. Note on two occasions the survey track was broken to survey off Loop Head.

The total distance travelled ranged from 47.7 to 63.9 nml (mean 54.8 nml) per survey, depending on sightings of bottlenose dolphins. Sometimes dolphins may be seen from a long distance and the survey vessel breaks the pre-determined track line to obtain images suitable for photo-id, for example in

Kilbaha Bay and in the mid-estuary. On two occasions, the track line was broken to survey waters off Loop Head following reports of dolphins present. Once photography of the group is completed the vessel will return to the location the track line was left and the survey continued. Each survey duration ranged from 345 mins to 510 minutes, with an average of 417min per survey .

2.2 Photo-identification

Images of bottlenose dolphins suitable for photo-identification were collected with Canon DSLR cameras. Each survey team had a Canon D7Mark ii, which is still considered one of the best cameras available for wildlife photography despite recent upgrades. D7Mark ii has GPS facility and can location stamp each image with latitude/longitude. MD also used a Canon 90d. All camera bodies were fitted with a 100-400mm lens. Canon 100-400 mm, f/4.5-5.6 L IS II USM or a Sigma 100-400 mm, f/5-6.3 DG 'Contemporary' These cameras can acquire images at 10.10 resolution and images were collected as jpg files. This equipment can collect images up to 7.5MB on a 32-64 GB card. Images were downloaded and sorted. Images to be processed were renamed using Imatch Phototools software.

All dolphin schools, defined as all dolphins within 100m radius of each other (Irvine *et al*., 1981), encountered were approached slowly and their position at the start and end of each encounter recorded using a hand-held GPS. Group size, behaviour (using Baker *et al.,* 2017) and the presence and numbers of calves were recorded. An attempt was made to photograph all dolphins in each school, and to obtain images of both left and right sides of each dorsal fin. Photo-identification was continued until all dolphins were considered photographed providing there was no negative reaction to the photo-identification attempt, e.g. avoiding vessel or excessive tail-slapping.

The number of adults, juveniles (sub-adults), calves and neonates within the group were recorded. An adult was defined as fully grown or known to be at least 5 years of age (from known individuals in the IWDG Shannon Bottlenose Dolphin Catalogue), juvenile was defined as approximately two-thirds the size of an adult or between 2 and 5 years of age (from the IWDG Shannon Bottlenose Dolphin Catalogue), calves as smaller than juveniles and known to be <2 years old. Neonates were determined from the presence of neonatal folds and were born within the survey period (June to September 2022).

2.3 Matching

The IWDG followed a standard protocol for sorting and matching images (Baker, 2015). All images were reviewed and all those badly out of focus, missing dolphins etc. were deleted. Sorting and matching was consistent with previous NPWS funded and recent IWDG surveys in the Shannon Estuary (Baker *et al.,* 2018a, 2018b, 2019). All dolphin images were sorted and graded from 1 to 3 following published criteria (Ingram, 2000; Englund *et al.,* 2007; 2008: Berrow *et al.,* 2010; Baker *et al.*, 2018a; 2018b).

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

Dorsal fins will be recorded as "left-side", "right-side" and "both sides" for each encounter. A unique catalogue of dorsal fins will be established for this project. Individual dolphins will be classified according to the extent of their natural marks, following Ingram (2000):

Severity Grade 1: Marks consisting of significant fin damage or deep scarring that can be considered permanent.

Severity Grade 2: Marks consisting of deep tooth rakes and lesions and minor cuts.

Severity Grade 3: Marks consisting of very superficial lesions or complete absence of them.

Photo-id matching was carried out by MD, with second checking by SL for quality assurance. Capture histories for Severity Grade 1: Left, Right and Both sides and Severity Grade 1+2 Left, Right and Both sides were created to derive mark-recapture abundance estimates.

Severity Grade 1 fin “left” and “right” example BDLS22-045 with significant damage to the fin and deep scaring.

Severity Grade 2 fin “left” and “right” example BDLS22-042 with minor cuts, see shallow notch at the apex of the fin, deep tooth marks and lesions.

Severity Grade 3 fin “left” example BLDS22-094 neonate with superficial rake marks.

2.4 Mark-Recapture Modelling

Mark-recapture modelling was carried out using the software programs MARK and CAPTURE (Version 6.2, Build 9200) by JO'B. All datasets were prepared and input into a closed model incorporating heterogeneity in capture probability (Chao M(th)) (Chao *et al.*, 1992). Multiple sample capture-recapture abundance estimates were generated based on the following assumptions of closed populations following Ingram (2000);

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.

The Akaike Information Criterion (AIC) values were calculated in the program MARK for each model to assess best fit (Akaike, 1974). The key parameters of the models 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 estimates, using a biased corrected estimate, 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.

The program 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. Estimates of abundance were calculated using left side, right side, and both side identifications. Bottlenose dolphins with Severity Grade 1 and 2 marks were used and not those with Severity Grade 3. Model results showed 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). The estimated total number of marked individuals in the population (Nhat) was calculated by the model.

We calculated estimates using dolphins re-captured 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 calculated all estimates using Photo Quality Grade 1 and 2 only.

3 Results

3.1 Survey Effort and Sightings

A total of twelve surveys were completed between June and September 2022, three in each month. All surveys were carried out in good sea conditions (≤sea-state 2). All survey effort was carried out in sea-state ≤3, with >95% in sea-state ≤2. A total of 44 sightings were made during the 12 transects with a mean of 3.7±1.4 per transect. Using best estimates from each sighting, a total of 350 dolphins were observed. rom these individual dolphins were identified (captured) on 316 occasions at a mean of 26.3±7.7 per transect (Table 1).

Table 1 Effort and sighting data for bottlenose dolphin survey in the Lower River Shannon SAC during 2022.

Survey	Date	Number of groups encountered	Best estimate of BND observed
1	1 June 2022	5	32
2	16 June 2022	4	22
3	22 June 2022	2	27
4	8 July 2022	2	31
5	9 July 2022	5	22
6	18 July 2022	6	33
7	8 August 2022	4	33
8	9 August 2022	2	32
9	21 August 2022	3	28
10	1 September 2022	2	22
11	10 September 2022	4	27
12	18 September 2022	5	41
Total		**44**	**350**

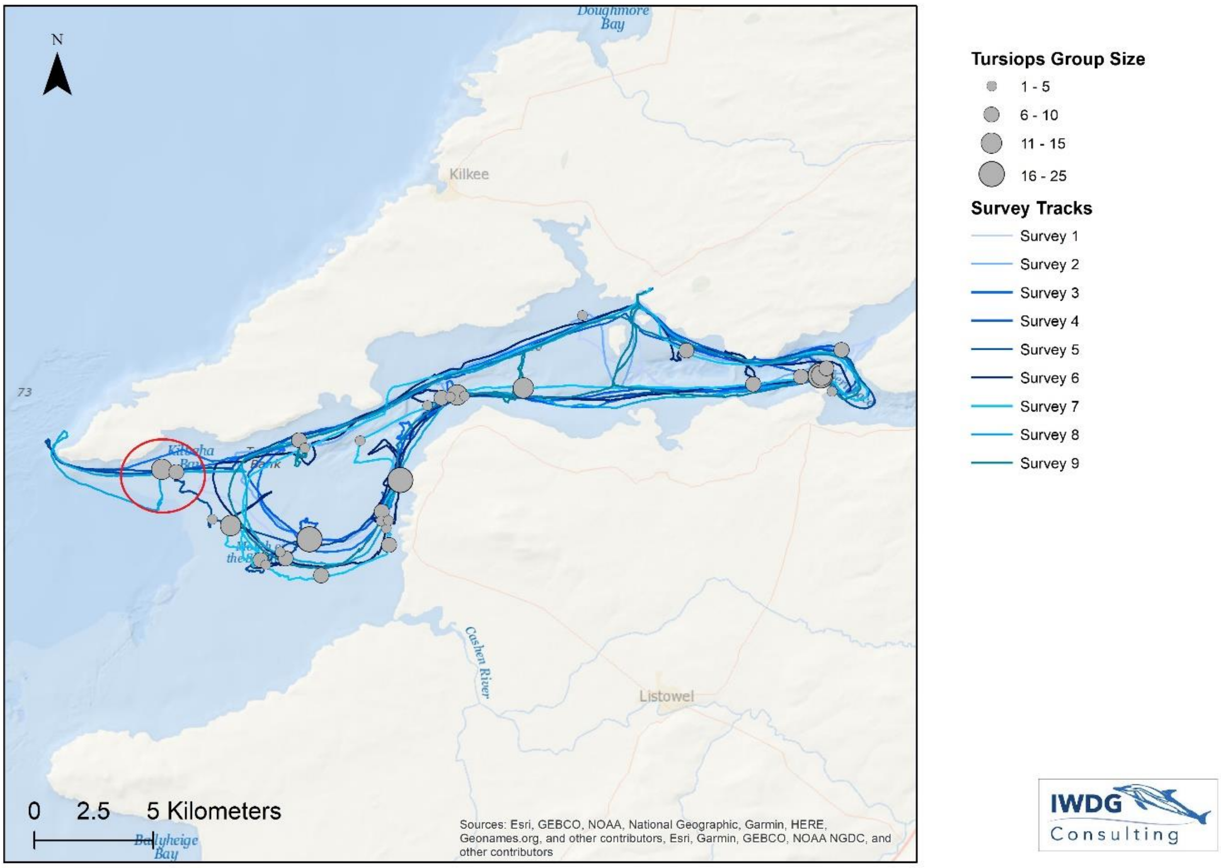


Figure 3 Bottlenose dolphin sightings and track-lines in the Lower River Shannon SAC during June to September 2022. Note dolphins recorded to the west of Kilbaha Bay (red circle) were included in the analysis.

Dolphins were recorded throughout the survey area with most sightings recorded in the outer estuary (Fig. 3). Concentrations were recorded off Tarbert towards the east of the survey area, off Beal Bar in mid-estuary and towards the southwest part of the survey track in the outer estuary.

No avoidance, or behaviour consistent with disturbance, was recorded. Total encounter time ranged 5 to 74 minutes with a median of 20 minutes which was consistent with the Code of Conduct in the Lower River Shannon SAC which requests boats to limit their time with each group of dolphins to a maximum of 30 minutes.

3.2 Images obtained for photo-identification

The primary objective for locating bottlenose dolphins was to obtain images suitable for photo-identification for use in mark-recapture modelling. Once an individual or group was encountered we attempted to obtain good images of both sides of the dorsal fin from all dolphins present. Using best estimate of group sizes a total of 350 dolphins were encountered over the 12 transects, of which 316 dolphins were identified from photo-id images which resulted in a total of 106 unique individuals (Table 2).

Of the 106 individuals identified, maturity was determined for 105. Of these 79 (75.2%) were considered adults, 14 (13.3%) juveniles with five calves and seven neonates.

Table 2 Number of dolphins identified during each survey and the cumulative total of individually recognisable dolphins within the Lower River Shannon SAC during 2022.

Survey Day	Number of individual dolphins captured	Cumulative number of dolphins captured
1	30	30
2	18	35
3	25	43
4	37	54
5	16	66
6	22	67
7	25	78
8	38	93
9	24	97
10	22	103
11	21	103
12	38	106
Total	**316**	**106**

Of the 106 individual dolphins identified, 57.5% (61 individuals) were considered to present grade 1 markings, 33.9% (36 individuals) and only 8.4% (9 individuals) with grade 3 fins (Table 3). Both sides of the dorsal fin were photographed of most 86.8% (92 individuals) dolphins with only 6 (5.6%) photographed only from the left side and 8 (7.5%) from only the right side (Table 3). In addition 5 calves were recorded, of which three were Fin Severity Grade 2 and two Fin Severity Grade 3. A total of 7 neonates were recorded during the survey period, all were categorised as Fin Severity Grade 3 and not included in the mark-recapture modelling.

Of the 106 individual dolphins identified only six (5.6%) were only captured from the left side and only eight (7.5%) were captured only from the right. The majority (86.7%) were captured on both sides (Table 3). Nine of the 106 individuals has fin grade severity 3 (9 of the 106 individuals) (Table 3). If we exclude those individuals with fins of mark severity grade 3, which are not used in the mark-recapture estimates then 91% (97 out of the 106 dolphins) were considered out best sample as these all had images from both sides of the dorsal fin and were of fin grade severity 1 and 2 (Table 3)

Table 3 Number of dolphins identified during each survey and the cumulative total of individual dolphins photographed in each Fin Severity Grade (1-3) during 2022.

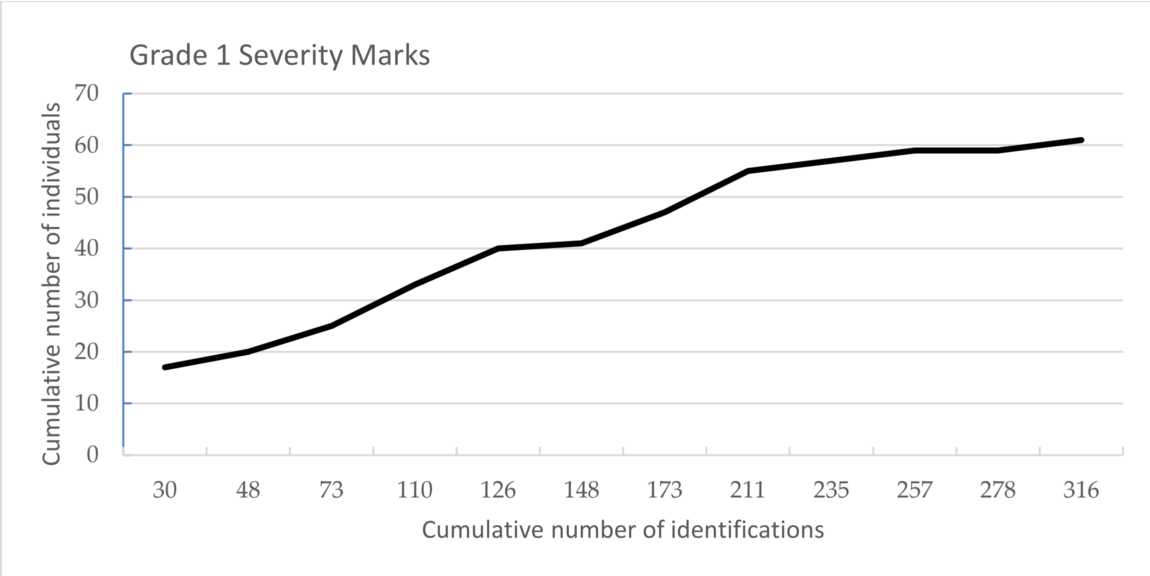
Survey Number	Number of individual dolphins identified	Cumulative number of dolphins identified	Number of individual dolphins identified	Cumulative number of dolphins identified	Number of individual dolphins identified	Cumulative number of dolphins identified
	Severity Grade 1 fin		Severity Grade 1+2 fin		Severity Grade 1+2+3 fin	
1	17	17	28	28	30	30
2	3	20	5	33	5	35
3	5	25	8	41	8	43
4	8	33	11	52	11	54
5	7	40	12	64	12	66
6	1	41	1	65	1	67
7	6	47	11	76	11	78
8	8	55	12	88	15	93
9	2	57	3	91	4	97
10	2	59	4	95	6	103
11	0	59	0	95	0	103
12	2	61	2	97	3	106

The cumulative numbers of new dolphins recorded throughout the survey in each fin category with the cumulative total of dolphins identified is present in Table 4. These data are used to prepare discovery curves (Fig. 4) which are used to explore whether all dolphins in the population have been captured (photographed) or whether there are likely some dolphins not captured to date.

Table 4 The number of marked dolphins used in the CAPTURE model

Fin Severity Grade	Both	Left Only	Right Only
Grade 1	52	4	5
Grade 2	32	2	2
Grade 3	8	0	1
Total	92	6	8

As the number of individual dolphins photographed increased throughout the survey the number of new dolphins identified during each survey decreased (Fig. 4). The data are presented as Grade 1 fins and Grade 1+2 fins combined as only a proportion of the dolphin population is marked. If we include Grade 3 fins into the data (see Table 4) the same trend was apparent. So although the number of new dolphins recorded is starting to plateau out the plot has not reached its asymptote suggesting not all the dolphins in the population had not been captured. Whether this indicates an open population with some individuals frequently ranging outside the study area and thus not available for capture or a closed population with some individual still not captured is not clear.



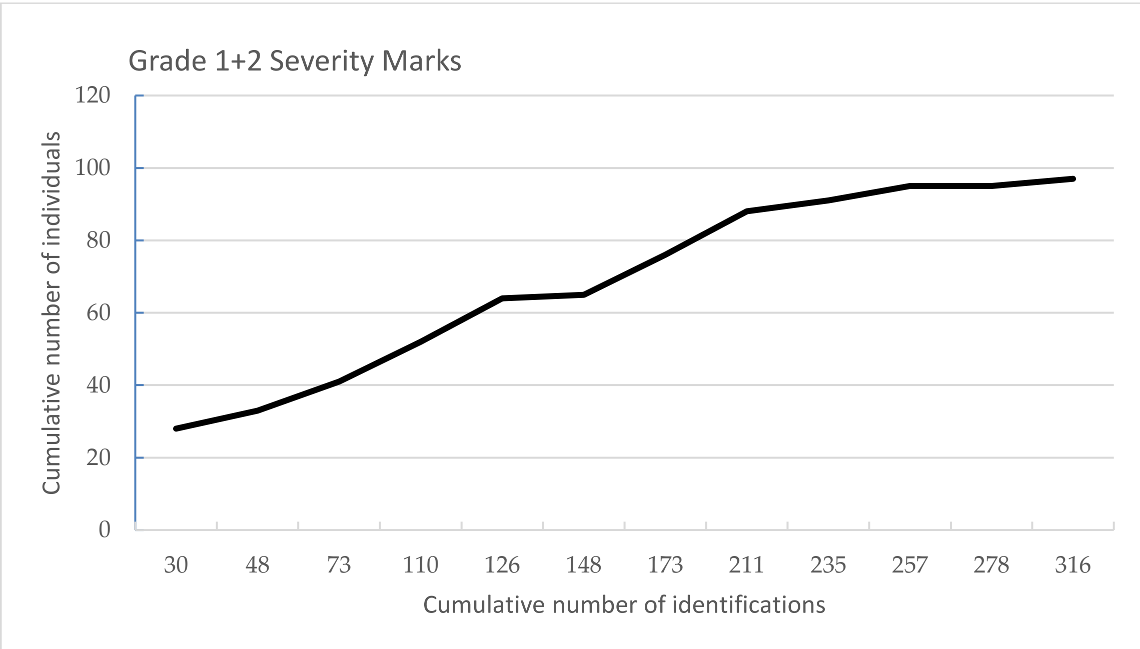


Figure 4 Discovery curves of individually recognisable bottlenose dolphins with grade 1 and 1+2 severity fin marks in the Lower River Shannon SAC during 2022.

3.3 Bottlenose dolphin abundance estimates

A total of 97 individual dolphins were used in the mark-recapture models. Of these 52 (53.6%) were of Severity Grade 1 and photographed from both sides of the dorsal fin and 32 (32.9%) were of Severity Grade 2 and photographed from both sides of the dorsal fin. Thus a subset of 84 individual dolphins were the most robust dataset for mark-recapture modelling. Of the images of the 106 dolphins identified only 5 individuals had Photo Quality 3 images of the left or right side, two of these had both sides photographed and at least one side Photo Quality 2, another 2 had only one side photographed. However these individuals could be identified as they had been encountered on other dolphin surveys carried out during the same period but were captured with Photo Quality 1 images. Only one individual of these with Photo Quality 3 was not photographed during other surveys and we could not be positive about its identification. Thus the vast majority of dolphins identified during this survey were captured with good quality images and could be included in the mark-recapture modelling.

Table 6 Model data used to estimate abundance of marked dolphins from CAPTURE model for Lower River Shannon SAC during 2022 (n= number of animals captured for estimate)

Fin Severity Grade	Dorsal Fin side	AIC	n	Nhat	Standard Error	95% Confidence Intervals
Grade 1	Both	352.3	172	64	5.80	58-82
	Both + Left only	357.8	175	71	7.16	62-92
	Both + Right only	348.4	177	76	8.00	66-99
	All					
Grade 1+2	Both	439.3	277	99	6.27	92-117
	Both + Left only	424.3	282	110	7.80	100-131
	Both + Right only	427.2	285	113	8.10	102-135
	All					

Fin Severity Grade	Dorsal Fin side	AIC	n	Nhat	Standard Error	95% Confidence Intervals
Grade 1	Both	352.3	172	64	5.80	58-82
	Both + Left only	357.8	175	71	7.16	62-92
	Both + Right only	348.4	177	76	8.00	66-99
	All					
Grade 1+2	Both	439.3	277	99	6.27	92-117
	Both + Left only	424.3	282	107	7.80	100-131
	Both + Right only	427.2	285	113	8.10	102-135
	All					

The sample size of identified individuals was high (Table 5; 84) and the number of Severity Grade 1 fins (Table 5; 52) were similar to Severity Grade 2 fins (Table 5: 32). The AICs were relatively high but quite consistent across all the models (Table 6). Here we present results from the analysis of Severity Grade 1 and Severity Grade 1+2 images to estimate abundance. Using images with Severity Grade 1+2 fins provided the most robust dataset and minimised violations of the assumption that all marks were correctly recorded and those animals do not lose their identifying marks. See Appendix I for capture histories of each individual dolphin.

Estimates of Nhat, which is the estimated total number of marked individuals in the population, ranged from 71 to 76 for Severity Grade 1 fins depending on whether they had been photographed from the Left, Right or Both sides and was 64 overall. When including Severity Grade 2 fins in the models this increased to 110-113 with a figure of 99 for all images combined (Table 7).

Table 7 Model outputs which includes estimates of θ (the proportion of dolphins with identifiable marks (Severity Grade 1 and Grade 1+2).

Fin Severity Grade	Dorsal Fin side	Nhat	Proportion of animals with marks (θ)	Abundance estimate	SE	Coefficient of variation	95% Confidence Interval
G1	Both + Left	31	0.63	112	16.7	0.15	80-145
	Both + Right	27	0.56	135	22.3	0.17	91-179
	Both	143	0.57	112	11.8	0.11	89-135
G1+2	Both + Left	110	0.98	112	8.3	0.07	96-128
	Both + Right	113	0.91	124	10.4	0.08	103-144
	Both	99	0.92	107	7.1	0.07	93-121

The proportion of dolphins with Severity Grade 1 and 2 identifiable marks is shown in Table 7. This ranged from 0.56 to 0.98 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:

Var N = N2 (varNhat/Nhat2 + 1- θ/nθ)

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 = SE2

The estimated abundance of marked individuals is increased according to the estimated proportion of marked individuals in the population (Table 7). An estimate of 0.57 was used for estimates using Grade 1 fins with images from both sides of the dorsal fin and 0.92 for Grade 1+2 fins. The abundance estimate varied from 112 ± 9, CV = 0.11 (95% CI =89-135) for both sides Severity Grade 1 images to 107 ± 7, CV = 0.07 (95% CI =93-121) for both sides of Severity Grade 1+2 images.

Data from Severity Grade 1 fins 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 the “both” category).

These two values were combined to give a final estimate of **116 ± 9, CV = 0.08 (95% CI = 98-133)**.

3.5 Juveniles, calves and neonates

A total of 13 adult-calf pairs were recorded during the surveys (see Appendix II). A total of 7 neonates were recorded during the study period. Six of the seven mothers (86%) with neonates were recorded during the surveys before they were subsequently sighted with neonates. All 7 mothers were recorded previously this season during Shannon Dolphin Project surveys without the neonate, thus confirming that these individuals were born within the survey period.

A total of 5 calves were recorded during the study period. All five mother calf pairs were sighted multiple times during the survey period. A total of 14 juveniles were also recorded. Of the 106 dolphins captured, 27 (25.5%) animals photographed are known second generation animals in the IWDG Shannon Dolphin Project Catalogue,.

Figure 5. Neonate (BDLS22-093) and mother (BDLS22-016) Bottlenose dolphin Catalogue Number recorded off Tarbert on 18 September 2022 (T12)

3.6 Site fidelity

Bottlenose dolphins in the Lower River Shannon SAC have been shown to demonstrate high levels of site fidelity especially over short summer field seasons. During the present study we photographed the same individuals on many occasions. 11.3% of the animals recorded during the survey were already in the IWDG Shannon Dolphin Project Catalogue pre 2000.

Individual dolphins were photographed on between 1 and 8 transects (Fig. 6); one individual (BDLS22-014) was recorded on eight of the 12 transects (66.7%), 8 (7.5% of the total number of individual dolphins photographed (106)) on both seven transects and (6.6%) on half (6) transects. A total of 35 (33.0%) individuals were only recorded on one transect and 21 (19.8%) on two transects. Of those dolphins only recorded once 24 of the 35 (68%) were grade 1 severity marked fins and 10 (28.6%) grade 2 mark severity fins showing that fin mark severity was not a factor in recapture rates but was a consequence of dolphin occurrence.

The IWDG carried out a number of other surveys outside the current contract but during the survey period as part of their ongoing monitoring programme. During these surveys at least 62 individuals were photographed outside the Lower River Shannon SAC and were matched to the known IWDG Shannon Dolphin Project Catalogue, and of these at least 18 (17%) were also captured during the survey. This shows that the Shannon Dolphins are highly mobile during the summer months.

There were no sightings of dolphins that have been catalogued as "coastal" (referred to as Conamara-Mayo in Nykänen et al., 2015) or "transient" groups of bottlenose dolphins within the survey area during the survey period.

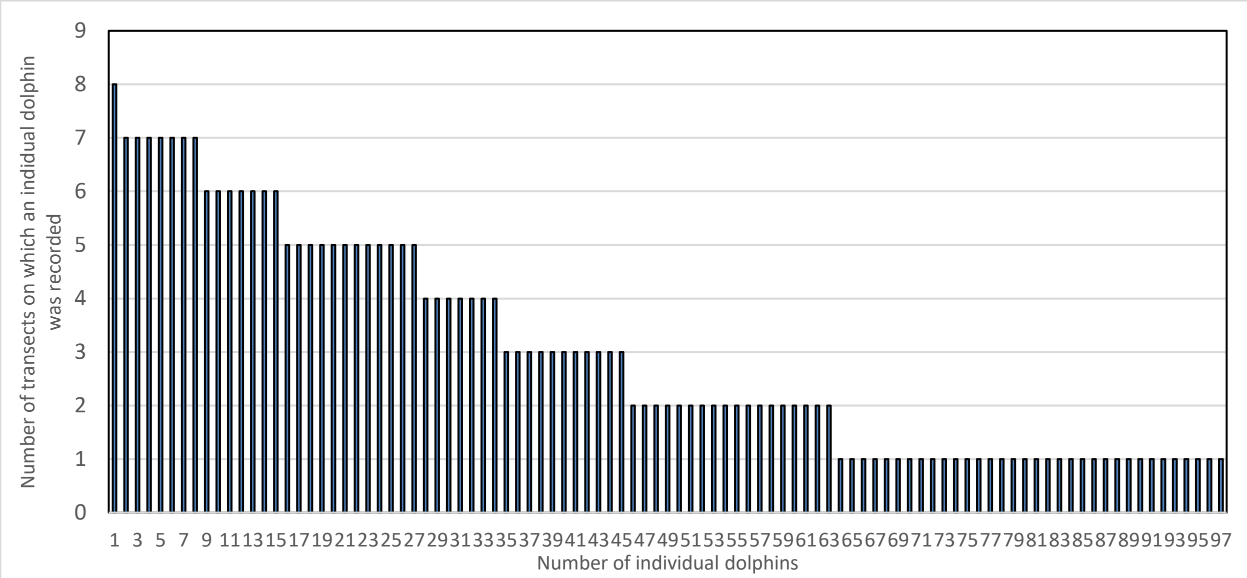


Figure 6 The number of transects individually recognisable bottlenose dolphins were captured in the Lower River Shannon SAC during 2022. (Total number of transects carried out = 12).

3.7 Additional sightings

In addition to Bottlenose dolphins, there were sightings of three other species of marine mammals (Table 8). Common dolphin and harbour porpoise are only very occasionally recorded in the Shannon Estuary while grey seals are frequently seen in small numbers.

Table 8 Number of sightings and group size of other marine mammal species recorded during surveys in the Lower River Shannon SAC during 2022

Species	Number of Sightings	Mean Group Size
Halichoerus grypus	9	1
Delphinus delphis	1	4
Phocoena Phocoena	2	1

4 Discussion

During the present survey of bottlenose dolphins in the Lower River Shannon SAC we encountered bottlenose dolphins on all 12 surveys at a rate 3.7±1.4 per transect. From these individual dolphins were identified on 316 occasions at a mean of 26.3±7.7 per transect. This resulted in a total of 106 individual dolphins identified with 84 Severity Grade 1 and 2 capture histories used in the models.

4.1 Bottlenose dolphins within the Lower River Shannon SAC

Bottlenose dolphins located largely throughout the study area within the Lower River Shannon SAC despite the area only covering less than one-third of the total SAC. The survey areas was chosen to be consistent with previous surveys dating back to 1997. Of the 105 maturity stage identified, 79 (75.2%) were considered adults, 14 (13.3%) juveniles with 5 calves and 7 neonates. For one individual (BDLS22-076) maturity was not categorised. This was higher than presented by Baker et al. (2018b) who stated that of the 145 extant individuals in 2015 they comprised 80 adults, 25 juveniles and 40 calves. This may be partly due to what is defined as juvenile or a calf. Mean inter-birth interval in the Shannon population was estimated by Baker *et al.* (2018b) to be 2.7 ± 0.6 and 3.5 ± 1.3 years.

Calving rate during 2202 was quite high. Rogan *et al.* (2018) reported 9 neonates and 3 calves while in 2015 only 2 neonates and 8 calves were reported (Rogan *et al.*, 2015). Our estimate of 7 neonates and 5 calves in 2022 was consistent with Baker *et al*. (2018b) who reported that the number of neonates per year varied between 3 and 10, with a mean of seven.

3 Site fidelity

The probability of capture is determined by the likelihood of individual dolphins occurring within the survey area, as well as the degree of marking. Also there is likely to be behavioural differences whereby some individuals (e.g. adults with calves) may be more difficult to capture as they may avoid boats.

Sighting rate can be calculated as the number of times an animal is encountered / total number of encounters (Nykänen *et al.*, 2015). The re-sighting rate of identified individual dolphins across the whole study area was 3.3 sightings for all individuals. Grade severity did not make much difference to this rate with grade 1 = 3.3, Grade 2 = 3.1 and Grade 3 = 3.1. This is a high sighting rate compared to the 2.5 sightings per individual presented by Englund *et al.* (2008). This suggests a high site fidelity of dolphins in the Lower River Shannon SAC, especially during the current survey. This to some extent is a result of sub-structuring within the population which can be broadly catergorised as "inner estuary" and "outer estuary" dolphins (Baker *et al.* 2018a). Of the 28 individual dolphins which were recorded on 5 or more transects, 85.7% (24 individuals) are part of the "inner estuary" sub-group.

Recent evidence suggests that Shannon dolphins are frequently recorded in Brandon and Tralee Bays and off Kilkee and Doonbeg, Co Clare (Levesque *et al.*, 2016: Ludwig *et al.*, 2021). It is likely that the Shannon dolphins have always used these areas outside the Lower River Shannon SAC but that it was not recorded until 2009 (Ryan and Berrow, 2011). However there is more recent evidence that some dolphins have "emigrated" outside the survey area. Ludwig *et al.* (2021) calculated survival rates of the Shannon dolphin population over a 27 year period. They showed that a total of 40 out of 141 marked individuals from the Shannon Catalogue were sighted at least once in Brandon and Tralee Bays across all years, and 16% of the marked population were sighted exclusively in the area in at least one year, with one individual in as many as four years. For ten individuals, encounters in Brandon Bay occurred after their last sighting in the Shannon Estuary, and four individuals have been exclusively sighted in Brandon Bay since 2008, providing evidence for temporal migration. Both survival rates and capture probabilities were comparatively low for individuals with low site fidelity to the Shannon Estuary, and survival rates of these individuals decreased even further toward the end of the Ludwig *et al.* (2021) study, reflecting a terminal bias. This bias was attributed to non-random temporal migration, and, together with high encounter rates in Brandon Bay, supported the hypothesis of range expansion. This is important if the population in the estuary was declining as the decline could be attributed to emigration rather than increased mortality.

Within the current study period (June to September 2022), at least 18 individuals that were recorded in the study area were also recorded outside the estuary, in Brandon Bay and off Doonbeg. For example

BDLS22-059 was recorded within the study area on transect 5 (9 July 2022) but then recorded 2 days earlier, 33km southwest in Brandon Bay on 6 July 2022. Similarly at least five dolphins (including BDLS22-096/BDLS22-101/BDLS22-102 and BDLS22-106) recorded within the study area on transect 9 (21 August 2022) were recorded 21 days earlier in a group of around 30 dolphins off Doonbeg 36 km to the north on 31 July 2022. All individuals identified during this NPWS survey are known to be part of the Shannon Dolphin population, having been recorded in the estuary on multiple occasions (IWDG, unpubl. data) with none considered part of the Coastal (or Conamara-Mayo) population (O'Brien *et al.*, 2009; Berrow *et al.*, 2021).

Rogan *et al.* (2018) reported that 55% of dolphin photographed in 2018 were reported in previous years meaning 45% were new to their long-term catalogue. Similarly in 2015, 23% of dolphins encountered had been observed since the late 1990s (Rogan *et al.*, 2015). Of the 106 individual dolphins recognised during the present study, at least 12 individuals have been documented for at least the last 20 years in the Shannon Estuary and one (BDLS22-058) is known since 1993 (Berrow *et al.*, 1996) making it at least 30 years of age.

4.4 Bottlenose dolphin abundance estimates

The current abundance estimate for bottlenose dolphin in the Lower River Shannon SAC is presented alongside previous estimates of this population (Table 8). The current estimate is within the 95% confidence intervals of previous estimates suggesting the population is stable. It should be noted that the CV of the estimate in the current study was much lower (0.08) than most previous estimates (Table 8) showing the estimate is very robust and has a correspondingly low 95% confidence interval range (35) compared to previous estimates (mean 54.7 range 39-67).

Table 8 Abundance estimates of bottlenose dolphins in the Lower River Shannon SAC.

Year	Estimate	Coefficient of Variation	95% Confidence Intervals	Reference
2022	**116±9**	**0.08**	**98-133**	**This study**
2018	139±15	0.11	121– 160	Rogan *et al*. (2018)
2015	114±14	0.12	90-143	Rogan *et al.* (2015)
2010	107±12	0.12	83-131	Berrow *et al.* (2010)
2008	114±17	0.15	85-152	Englund *et al.* (2008)
2006-2007	140±12	0.08	125-174	Englund *et al.* (2007)
2003	121±14	0.12	103-163	Ingram and Rogan (2003)
1997	113±14	0.14	94-161	Ingram (2000)

Our estimate was 16.5% lower than that reported in 2018 by Rogan *et al.* (2018) but similar to that reported in 2015 (114±14; Rogan *et al.*, 2015) and 2008 (114±17; Englund *et al.*, 2008). The only previous estimate with a CV under 0.10 was that of Englund *et al.* (2007) who carried out a total of 29 surveys between June 2006 and June 2007; the only time photo-id has been collected throughout the year to estimate abundance. Interestingly if we compare the current estimate to that of Englund *et al.* (2007) then this represents a 17.1% decline in abundance over a 16 year period.

Estimating statistical error enables an estimate of abundance or population size to be presented with a measure of precision. The measure of precision expresses the level of uncertainty we have in the estimate (Hammond *et al.*, 2021). In the current survey we have high confidence in the estimate as the CV is very low but less confidence in previous estimates with higher CVs. This is important when we consider the sensitivity of the method used to detect change.

Englund *et al.* (2007) explored how abundance estimates varied with increasing number of transects within a survey. They showed that there was a marked improvement in power to detect population change when using CVs < 0.10. Englund *et al.* (2008) updated this power analysis and showed that as the sighting frequency per individual increased the CV decreased and recommended monitoring the sighting frequency during a sampling season to get an indication of progress when aiming for a target estimate CV.

Englund *et al.* (2007; 2008) also used a power analysis to explore how long it would take to detect a population change of 5% per annum using different sampling strategies (i.e. number of years between surveys). Using the current triennial sampling strategy and with estimate precision (CV) <0.10 a 5% per year population change would not be detected until four reporting cycles (i.e. 12 years). However, an annual reporting cycle will detect the same rate of population change within seven years (Englund *et al.* 2007). Englund *et al.* (2008) suggested that an annual reporting cycle was preferred to obtain high power to detect change, but if resources were limited it is preferable to decrease reporting frequency than reduce survey effort in any given reporting year to ensure a low CV around the estimate.

Overall the estimate from 2022 is consistent with all previous abundance estimates from the Lower River Shannon SAC suggesting the population is stable, within the ability of the current sampling strategy to detect change.

4.3 Recommendations

1. Consideration should be given to increasing the number of transects carried out during abundance estimate surveys to enable the discovery curve to reach a plateau indicating the majority of the population has been captured to improve precision of the analysis.
2. The required CV from these estimates should be reduced from 0.12 to <0.10 to improve the precision of the estimate and thus the power of this monitoring strategy to detect population change.
3. Photo-id should be continued throughout the year to improve the abundance estimate (reduce CV) but also to provide estimates of winter/spring (October-May) abundance.
4. Consideration should be given to carrying out annual surveys, not only to increase the ability of mark-recapture modelling using photo-id data to detect population changes over reasonable time frames, but to obtain data on calving and survival rates.
5. Photo-id effort needs to be carried out outside the traditional survey route in the Lower River Shannon SAC and targeting additional sites such as in Brandon Bay, Co Kerry and off Kilkee and Doonbeg, Co Clare, which are known to be regularly used by Shannon dolphins.

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Appendix I: Capture histories of individual bottlenose dolphins (Severity Grade 1 to 3 are presented but only Grade 1 and 2 were used in abundance estimates)

NWPS Code	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
BDLS22-001	1	1	1	1				1	1			1
BDLS22-002	1	1	1	1					1		1	1
BDLS22-003	1	1		1	1				1			
BDLS22-004	1	1		1				1	1		1	
BDLS22-005	1	1		1							1	1
BDLS22-006	1	1		1				1	1		1	1
BDLS22-007	1	1		1				1	1		1	1
BDLS22-008	1		1	1		1				1		
BDLS22-009	1		1	1		1				1		
BDLS22-010	1					1						
BDLS22-011	1					1						
BDLS22-012	1											
BDLS22-013	1		1							1		1
BDLS22-014	1	1	1	1		1		1	1		1	
BDLS22-015	1		1	1		1			1		1	
BDLS22-016	1	1		1				1	1			1
BDLS22-017	1		1				1		1			
BDLS22-018	1						1		1			
BDLS22-019	1		1				1			1		
BDLS22-020	1	1		1		1		1			1	1
BDLS22-021	1		1	1			1			1		
BDLS22-022	1		1	1						1		1
BDLS22-023	1		1	1		1				1		1
BDLS22-024	1		1	1						1		1
BDLS22-025	1	1		1				1			1	1
BDLS22-026	1	1		1				1			1	1
BDLS22-027	1		1			1				1		1
BDLS22-028	1			1		1			1			1
BDLS22-029	1	1		1		1		1				1
BDLS22-030	1		1							1		
BDLS22-031		1	1	1		1		1			1	1
BDLS22-032		1		1				1			1	1
BDLS22-033		1		1		1		1	1		1	1
BDLS22-034		1		1								1
BDLS22-035		1	1	1		1	1		1		1	
BDLS22-036			1					1				
BDLS22-037			1									
BDLS22-038			1					1		1		
BDLS22-039			1									1
BDLS22-040			1			1			1	1		
BDLS22-041			1			1			1	1		

BDLS22-042			1							1		
BDLS22-043			1									
BDLS22-044				1	1		1					
BDLS22-045				1	1		1					
BDLS22-046				1			1					1
BDLS22-047				1	1		1					
BDLS22-048				1						1		
BDLS22-049				1			1	1				
BDLS22-050				1		1		1				
BDLS22-051				1		1		1			1	
BDLS22-052				1		1		1			1	
BDLS22-053				1		1			1		1	1
BDLS22-054				1		1			1		1	1
BDLS22-055					1			1				
BDLS22-056					1			1				
BDLS22-057					1							1
BDLS22-058					1							
BDLS22-059					1							
BDLS22-060					1		1					
BDLS22-061							1					1
BDLS22-062					1							
BDLS22-063					1			1				
BDLS22-064					1							
BDLS22-065					1		1					
BDLS22-066					1		1					
BDLS22-067					1		1					
BDLS22-068						1		1			1	
BDLS22-069							1					
BDLS22-070							1					
BDLS22-071							1					
BDLS22-072							1					
BDLS22-073							1					
BDLS22-074							1					
BDLS22-075							1					
BDLS22-076							1					
BDLS22-077							1					
BDLS22-078							1					
BDLS22-079								1				
BDLS22-080								1				
BDLS22-081								1				
BDLS22-082								1				
BDLS22-083								1				1
BDLS22-084								1				
BDLS22-085								1				
BDLS22-086								1				
BDLS22-087								1				

BDLS22-088								1				
BDLS22-089								1				
BDLS22-090								1				
BDLS22-091								1	1			1
BDLS22-092								1	1			1
BDLS22-093								1			1	1
BDLS22-094									1		1	1
BDLS22-095									1			
BDLS22-096									1			
BDLS22-097									1	1		
BDLS22-098										1		1
BDLS22-099										1		1
BDLS22-100										1		
BDLS22-101										1		
BDLS22-102										1		1
BDLS22-103										1		1
BDLS22-104												1
BDLS22-105												1
BDLS22-106												1

Appendix II: Adult-calf/neonate pair associations

Mother	Calf	Calf Age
BDLS22-001	BDLS22-092	Neonate
BDLS22-002	BDLS22-095	Neonate
BDLS22-006	BDLS22-007	Calf
BDLS22-008	BDLS22-009	Calf
BDLS22-010	BDLS22-011	Calf
BDLS22-013	BDLS22-099	Neonate
BDLS22-016	BDLS22-093	Neonate
BDLS22-025	BDLS22-026	Calf
BDLS22-027	BDLS22-104	Neonate
BDLS22-031	BDLS22-094	Neonate
BDLS22-039	BDLS22-105	Neonate
BDLS22-040	BDLS22-041	Calf