An assessment of the breeding population of grey seals in the Republic of Ireland, 2005

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Oliver Ó Cadhla[1], Denis Strong[2], Ciaran O'Keeffe[2], Mary Coleman[1], Michelle Cronin[1], Callan Duck[3], Tony Murray[2], Pascal Dower[2], Richard Nairn[4], Paul Murphy[5], Pat Smiddy[2], Cyril Saich[2], David Lyons[2], Lex Hiby[6]

1. **COASTAL & MARINE RESOURCES CENTRE,**
ERI, University College Cork,
Lewis Glucksman Marine Facility,
Irish Naval Base, Haulbowline,
County Cork.
IRELAND

2. **NATIONAL PARKS & WILDLIFE SERVICE,**
7 Ely Place,
Dublin 2.
IRELAND

3. **NERC SEA MAMMAL RESEARCH UNIT,**
Gatty Marine Laboratory,
University of St. Andrews,
St. Andrews, Fife KY16 8LB.
SCOTLAND

4. **NATURA ENVIRONMENTAL CONSULTANTS LTD.,**
Broomhall Business Park, Rathnew,
County Wicklow.
IRELAND

5. **EIRECO ENVIRONMENTAL CONSULTANTS,**
Ballyvaughan,
Co. Clare.
IRELAND

6. **CONSERVATION RESEARCH LTD.,**
110 Hinton Way,
Cambridge, CB2 5AL.
ENGLAND

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Cover photo: Grey seal mother and white-coated pup on an uninhabited Irish island. © Oliver Ó Cadhla

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SUMMARY

The population of the grey seal (*Halichoerus grypus*) in the Republic of Ireland was assessed by means of a comprehensive baseline survey conducted during the 2005 breeding season.

The primary objectives of the research were:

1. To carry out a definitive comprehensive survey meeting Irish data requirements and delivering a reliable breeding population estimate for grey seals;
2. To fulfil baseline monitoring requirements under the EC Habitats Directive;
3. To establish an effective methodological base from which future monitoring can be conducted;
4. To provide information to assist in the formulation of effective site management plans for this protected species;
5. To provide up to date information for addressing national seal population management issues.

Detailed planning and team training for a coordinated aerial and ground survey of the Republic of Ireland took place during the spring and summer of 2005. Field surveys began in late August 2005 and continued until early December. Digital aerial photography and videography were used extensively to collect aerial imagery of grey seal pups. Photographs were compared with parallel data gathered on the ground in order to assess methodological efficiency. Ground- and boat-based site visits were carried out at islands off Co. Dublin and Co. Wexford, and on foot along the coastlines of east Co. Cork and Co. Waterford, allowing the prioritisation of aerial survey effort along the Atlantic seaboard. The data acquired by these complementary methods yielded the following key results:

- The Republic of Ireland was surveyed intensively during the 2005 grey seal breeding season and its population assessment was a considerable logistical and operational success;
- A total of 1,574 grey seal pups was estimated to have been born in the Republic of Ireland during the 2005 breeding season. While the figure is an approximation it is considered a reliable and repeatable quantitative descriptor for future population assessments;
- The corresponding population estimate for the Republic of Ireland in 2005 was 5,509—7,083 grey seals of all ages. This represents an appropriate robust national baseline figure for the species;
- Increases in annual pup production were described at several key regional breeding colonies;
- Recorded pup mortality was relatively low, based on data from both aerial and ground counts;

- Grey seal distribution during the 2005 breeding season was found to be concentrated along the Atlantic seaboard with more isolated regional concentrations off the Dublin and Wexford coasts;
- Significantly lower grey seal pup production and distribution were recorded along the mainland coasts of Counties Cork, Wicklow and Wexford compared to counties along the Atlantic coast, a feature most likely due to poor availability of sheltered, undisturbed breeding habitat.
- No direct evidence of grey seal breeding was recorded in 2005 along the coasts of Counties Leitrim, Waterford, Meath, or Louth.
- Ground-truthing experiments performed close to or on selected aerial survey dates were successful in providing validation for independent aerial and ground count data. These showed close agreement in most cases while highlighting areas of potential improvement;
- The methods and data presented in this report are discussed and a number of recommendations made, based on the study's findings.

1. INTRODUCTION

1.1 Background to the Study

The grey seal (*Halichoerus grypus* Fabricius 1791) (Plate 1) is one of two seal species which breed around the Irish coast. Records of its occurrence in the Republic of Ireland date to 1837 (O'Gorman, 1963). Like the smaller harbour seal (*Phoca vitulina vitulina*), grey seals have established terrestrial colonies (or *haul-outs*) around the island, which they leave when foraging or transiting between sites, for example, and to which they return to breed, rest, moult, engage in social activity, etc (*see* Bonner, 1990).

Unlike harbour seals, which in Ireland tend to inhabit inshore bays, coves and estuaries (Lockley, 1966; Summers *et al*., 1980; Cronin *et al*., 2004), grey seals generally select more remote haul-out sites on rocky skerries, uninhabited islands, isolated mainland beaches and in sea-caves (Lockley, 1966; Summers, 1980, 1983; Kiely, 1998; Kiely *et al*., 2000). The main periods in Ireland when grey seals spend several weeks at haul-out sites, and larger numbers of seals are recorded, are during the annual moult (November to April) and breeding seasons (late August to December) with a slight overlap in phases occurring in late November and early December (Kiely, 1998; Kiely *et al*., 2000).

Plate 1. Adult grey seal on the grassy summit of a small island during the breeding season.

Grey and harbour seals are strictly protected in the Republic of Ireland under the Wildlife Act, 1976 and the Wildlife (Amendment) Act, 2000. They are also listed under Annex II of the European Union's Habitats Directive (92/43/EEC) as species of Community Interest, whose conservation requires the designation of Special Areas of Conservation (SACs). In the latter part of the 1990s, the National Parks & Wildlife Service (NPWS) proposed all of the major known breeding sites as candidate SACs, ten sites for the grey seal (Appendix I) and seven for the harbour seal (*see* Cronin *et al*., 2004).

The first field assessments of Irish grey seal and harbour seal population size were carried out by R.M. Lockley during the 1964-65 breeding seasons. This research delivered a

baseline population estimate of 2,500 grey seals of all ages (Lockley, 1966). Following the species' protection in the Republic under the Wildlife Act (1976), a second national grey seal "census" was conducted between 1978 and 1983 by the then Forestry & Wildlife Service, using a combination of aerial reconnaissance and ground surveys (P.J. Warner, NPWS, *unpubl.*). Preliminary information highlighted the west coast as a region of importance for grey seals, while isolated breeding sites were also identified along the northwest, south and east coasts (Warner, 1979; Summers, 1980). Due to operational constraints these survey efforts became concentrated at the principal known colonies on the Blasket Islands, Co. Kerry and Inishkea group of islands in northwest Co. Mayo. During the 1978-1982 period a series of illegal culling and disturbance incidents prompted Summers (1983) to revise an earlier minimum population estimate downwards to 2,000-2,500 grey seals.

Monitoring by members of the Wildlife Service continued locally into the 1990s (e.g. McMahon, 1989; *see* Lyons, 2004) when a number of dedicated studies into grey seal population biology began at key colonies in Ireland (Table I). Efforts to determine population size via a range of methods gathered momentum between 1994 and 2000, with several authors (BIM, 1997; Kiely, 1998; Kiely *et al*., 2000) recommending that a new national population assessment be undertaken.

Table I. Summary of research into grey seal population size in the Republic of Ireland: 1994-2004.

YEAR(S)	REFERENCES	SEASONS	LOCATIONS	ASSESSMENT TYPE
1994	BIM, 1997	Breeding	Inishkea Group	Pup through-count
1994	Kiely, 1998	Breeding	Inishkea Group	Reconnaissance
1995-97	Kiely, 1998 Kiely & Myers, 1998	All	Inishkea Group Blasket Islands Saltee Islands	Pup through-count Haul-out abundance Photo-ID Mark-recapture
1997-99	Kiely *et al*., 2000 Lidgard *et al*., 2001	All	Saltee Islands Irish Sea Eastern Celtic Sea	Pup through-count Haul-out abundance Photo-ID Mark-recapture
1997-99	BIM, 2001	Breeding	Inishkea Group Southwest Mayo Northwest Galway Donegal coast	Pup through-count Reconnaissance
2002	Ó Cadhla & Strong, 2003	Breeding	Inishkea Group	Pup through-count
2003	Cronin *et al*., 2004 Cronin *et al*., 2007a	Summer	Rep. of Ireland	National haul-out count
2003	Cronin & Ó Cadhla, 2004 Cronin *et al*., 2007b	Breeding	Blasket Islands	Aerial population assessment
2003	Cronin & Ó Cadhla, 2004 Cronin *et al*., 2007b	Breeding	Inishkea Group Donegal coast	Single aerial count Reconnaissance
2003-04	D. Strong & G. O'Donnell, NPWS, *unpubl.*	Breeding	North Galway	Single aerial count Reconnaissance
2004	Ó Cadhla *et al*., 2005	Breeding	Slyne Head islands Hen Island	Pup through-count
2004	Ó Cadhla *et al*., 2006	Breeding Moult	Southwest Mayo Northwest Galway	Single ground count Reconnaissance Aerial scoping survey

The studies carried out between 1995 and 2000 facilitated a revision of the Irish minimum population estimate to over 4,000 grey seals (Ó Cadhla & Mackey, 2002). Further field research was conducted between 2002 and 2004 to reduce significant data gaps in western Ireland and to investigate methodological options for a full national population assessment, building on experience gained in the 2003 harbour seal survey (Cronin *et al*., 2004) to test aerial methods for counting grey seals (Cronin & Ó Cadhla, 2004; D. Strong & G. O'Donnell, NPWS, *unpubl*.; Ó Cadhla *et al*., 2006; Cronin *et al*., 2007b). In November 2004, evidence of an illegal cull was discovered at the Blasket Islands. Approximately 60 grey seals had been killed, most of them newborn pups (P. Foley, NPWS, *unpubl*.).

Meanwhile in Northern Ireland the first combined aerial and ground assessment of its grey seal population was carried out in 2002 by the Environment & Heritage Service (EHS) and Sea Mammal Research Unit (SMRU). While breeding surveys did not cover the entire season, the number of pups likely to be born annually, an index of all-age population size (*see* 2.1, 2.7.5), was considered to be comparatively low (i.e. total <100 pups; C.Duck, SMRU, *pers. comm.*). Although the proportion of grey seals breeding in Northern Ireland is thought to be small, data gathered in the neighbouring Republic provides significant regional value and context to Irish and UK research as a whole. It would also provide an opportunity for including counts from Northern Ireland to yield an all-Ireland minimum population estimate for the species.

1.2 Rationale

Reliable population estimates and up-to-date information on grey seal distribution on land and at sea are needed for the successful conservation of this Annex II species in Ireland, and are required under Articles 11 and 17 of the Habitats Directive. These data are also necessary for environmental impact assessment and species management plans, and are crucial to the investigation and understanding of coastal and marine ecological issues. For example, competition with commercial fisheries for prey resources, accidental by-catch in fishery operations, outbreaks of disease, human impacts on the coastal environment, etc.

An outbreak of Phocine Distemper Virus (PDV) in the summer of 1988 caused the deaths of approximately 17,000 seals in western Europe between April 1988 and June 1989 (Van der Toorn, 1990). Mortality appeared to occur predominantly in harbour seal populations, although grey seals were also known to be affected by PDV to a lesser degree (Hall *et al*., 1992). In May 2002, a second major outbreak attributed to the PDV virus resulted in the deaths of c. 22,500 harbour seals in the Baltic Sea, the Wadden Sea and the North Sea (TSEG, 2001).

In the Republic of Ireland, the absence of reliable national population estimates for both seal species in 2002 precluded any scientific assessment of impact due to disease and the conservation status of grey and harbour seal populations remained unknown. This large-scale shortfall in data was first addressed by the development and completion of a national harbour seal population assessment in August 2003 (Cronin *et al*., 2004; Cronin *et al*., 2007a). Following ongoing discussions between interested government and research parties it was decided that the Republic of Ireland's grey seal population should also be assessed by means of a complete survey in 2005.

1.3 Research Objectives

The primary objectives of the grey seal population assessment were as follows:

1. To carry out a definitive comprehensive survey meeting Irish data requirements and delivering a reliable breeding population estimate for grey seals;
2. To fulfil baseline monitoring requirements under the EU Habitats Directive;
3. To establish an effective methodological base from which future monitoring can be conducted;
4. To provide information to assist in the formulation of effective site management plans for this protected species;
5. To provide up to date information for addressing national management issues.

1.4 Partnership

The project was funded by the National Parks & Wildlife Service of the Department of the Environment, Heritage and Local Government. Principal partners to NPWS were the Coastal & Marine Resources Centre (CMRC), University College Cork, the Sea Mammal Research Unit (SMRU), University of St. Andrews. Research on selected islands in Co. Dublin were jointly carried out by NPWS and NATURA. All of the above were involved in the design and planning of the project from its inception in late February 2005 and a large project team (Appendix II) was assembled for the purposes of executing all survey elements. In this context the Irish Air Corps also played a major role. Contact was also established with the Environment & Heritage Service, Northern Ireland during the course of the project, allowing the transfer of recent experience and relevant information, thereby strengthening links between statutory bodies on both sides of the border.

2. METHODS

2.1 Introduction

Like other members of the seal family (*Phocidae* or *'true seals'*), grey seals follow an annual cycle (Bonner, 1972, 1990) that includes (i) a prime foraging season followed by (ii) the breeding season and (iii) the annual moult period. Within the species' North Atlantic range, the timing and span of these seasons may depend on geographic location and other natural variables (e.g. individual age, sex, physiology, environment). For example, the annual moult season for grey seals in Ireland is somewhat earlier than generally described by Bonner (1990), beginning as early as November for adult females and juveniles and continuing up to April for adult males (Kiely, 1998).

Due to differences in individual life histories, behaviour and seasonal cycles, the entire population of grey seals is never fully available for counting. Yet the presence ashore of significant portions of a population during breeding and moulting facilitate the assessment of population size over a large geographic area. In seeking to determine the species' population status around the Irish coast, recent research efforts in the Republic have focused on important local/regional colonies (Table I), generally using ground-based methods whether for (a) breeding population assessments (e.g. Summers, 1983; Kiely & Myers, 1998), or (b) mark-recapture estimation via photo-identification (Hiby & Lovell, 1990) (e.g. Kiely, 1998; Kiely *et al.*, 2000). While such methods have been successful, they require safe access to remote and often exposed haul-out sites with small teams of experienced researchers to cover the necessary search area and gather data. They also require licensing and strict survey protocols to limit disturbance to haul-out groups and sensitive breeding colonies.

Plate 2. NPWS conservation ranger dye-marking a grey seal pup's white coat, October 2004.

Grey seal mothers, like most other seals, generally give birth to one pup per year of their adult life (Bonner, 1990). Pups are born ashore bearing a distinctive white coat of fur (Plate 2) that is moulted after a period of several weeks on land (Coulson & Hickling, 1964; Boyd &

Campbell, 1971; Bonner, 1972). This definable cohort is available for counting at the same time each year. Provided additional information on growth and survival rates, female fecundity and other life history parameters are available, it is possible to statistically derive an estimate of total population size based on the number of pups produced in that year (Ward *et al*., 1987).

However female grey seals do not all give birth at the same time; during the August–December season as a whole, successive new pups are nursed and weaned ashore before they leave the colony and enter their first marine phase of life. Thus estimation of pup production at a breeding colony must rely on either (i) **Direct measurement**, i.e. the counting of every pup born, or (ii) **Indirect measurement**, i.e. using pup count samples from regular site-visits to model overall production. While it may be possible at a few select sites, direct observation of every grey seal birth around the coast of Ireland is not feasible, given the exposed environments at which grey seals breed and the risk of excessive disturbance to the species. Thus indirect measurement has commonly been used to investigate pup production at individual breeding colonies and to deliver population estimates (*see* Table I).

Since 1994 'through-counting' (Boyd & Campbell, 1971) has been the preferred method of pup production estimation in the Republic of Ireland (e.g. Kiely & Myers, 1998; Lidgard *et al*., 2001). It involves visits to breeding sites at intervals of 10-15 days, temporarily marking individual pups with a dye solution (Plate 2) and classifying each living pup encountered by its developmental stage (Table II; *after* Radford *et al*., 1978; Kovacs & Lavigne, 1986). Dead pups are also recorded, marked and removed from the shoreline where they might be washed into the sea or obscured by beach material.

By this sampling method, pup production is assessed cumulatively over the breeding season. To derive an all-age population estimate, the total observed pup production is then subject to a multiplication factor based on grey seal life history parameters developed by Hewer (1964) and later modified by Harwood & Prime (1978). The total production recorded, however, represents the minimum pup production for the site, since it depends on the frequency and success of site-visits, does not account for the natural birth-trend at the colony or for unobserved losses due to pups that are born and leave the site between counts, whether alive or dead. In 2005, this combined margin for error was felt to be unacceptable on a national scale and efforts were made to address it through improved methodology and statistical analysis (*see* 2.7.5).

In carrying out this survey, labour-intensive and weather-prone methods such as through-counting could not be relied on to deliver an effective assessment of pup production over such a large coastal area, particularly along the Atlantic coast. Thus in its initial stages, aerial survey methods were factored into the project design as an important potential feature, based on (i) international practice (e.g. Ward *et al*., 1987; Hiby *et al*. 1988; Bowen *et al*., 2003; C. Duck *et al*., SMRU, *unpubl*.), (ii) field experience gained in the UK and Ireland by CMRC and NPWS researchers; (iii) the successful operation of the 2003 national harbour seal survey (Cronin *et al*., 2004), and (iv) aerial survey trials for grey seals conducted in 2003-2005 (D. Strong & G. O'Donnell, NPWS, *unpubl*.; Ó Cadhla *et al*., 2006; Cronin *et al*., 2007b). Yet a significant barrier remained in determining the appropriate scope and methodology for the 2005 population assessment, namely the shortage of recent breeding data from a large area of Ireland's coastline. To address this deficit in information, a number of measures were taken at the outset of the project.

Table II. The developmental stages into which grey seal pups are classified during ground counts.

PUP STAGE	AGE*	CHARACTERISTICS	EXAMPLES
Stage I	0-2 days	THIN BAGGY-SKINNED BODY YELLOW-STAINED or WHITE NATAL FUR CONSPICUOUS UMBILICAL CORD DOCILE AND POORLY COORDINATED	
Stage II	3-7 days	SMOOTHER BODYLINE, FEW LOOSE FOLDS NECK STILL DISTINGUISHABLE UMBILICAL CORD ATROPHIED AWARE AND COORDINATED	
Stage III	7-15 days	ROUNDED OR BARREL-SHAPED BODY NECK THICKENED/INDISTINGUISHABLE MOULTING FROM HEAD OR FLIPPERS MAY BE AGGRESSIVE ON APPROACH	
Stage IV	16-20 days	ROUNDED/BARREL-SHAPED BODY PARTIALLY MOULTED FROM TORSO HEAD AND FOREFLIPPERS MOULTED MOBILE/AGGRESSIVE ON APPROACH	
Stage V	18-25+ days	FULLY MOULTED TO SHORT FUR COAT *(< 100 cm² OF NATAL COAT REMAINING)* SPECKLED COLOURATION VARIES AGGRESSIVE AND MOBILE	

[Based on published information and research experience. *Ages given are intended as approximations and some variation may occur depending on the health and physical condition of individual pups].

2.2 Data Review: 1964—2004

In order to establish and verify all known grey seal breeding sites in the Republic of Ireland a review of grey seal data was carried out between February and May 2005. This covered all published and unpublished information available (*see* 1.1), dating back to R.M. Lockley's original study in 1964-65. The review process incorporated field reports and notes written by individual NPWS staff over the 1978-2004 period, included material compiled and presented in Lyons (2004), and also a new questionnaire-survey circulated to all NPWS field staff. Further efforts were made to verify records and gather additional

information through liaison with members of the wider scientific community, the Irish fishing industry, the Commissioners of Irish Lights, island inhabitants, naturalists and other members of the public.

2.3 Preliminary Reconnaissance

In parallel with the data review, a series of aerial surveys of the coastline was conducted with the Irish Air Corps. This reconnaissance, carried out in single-engine *Cessna 172* aircraft, was necessary due to continued sparse breeding data from significant portions of the Irish coastline, largely as a result of historically low coverage. The purpose of these scoping surveys was:

a. to identify sites with potential habitat for grey seal breeding around the Irish coast;
b. to familiarise the team with coastal topography and flying conditions in the study area;
c. to examine potential aerial survey methodologies, including flight planning options;
d. to acquaint the research team with airfields that might be used in the national survey;
e. to determine aerial journey times within regional areas;

Once the surveys were completed, an additional flight was also carried out in an Air Corps CASA patrol aircraft to assess its suitability for offshore use and for aerial photography during the breeding season.

2.4 Survey Design

Preliminary research, the search for suitable survey aircraft, airfields and staff availability contributed to the development of an overall survey design through consultation and coordination between the project partners. An underlying principle throughout was the appropriate use of resources within the weather conditions that prevail around the Irish coast between September and December.

Based on all information available, a set of 148 coastal locations were identified for survey among five broad Search Areas (Fig. 1):

(A) Northwest - Co. Sligo, Co. Donegal
(B) West - Co. Clare, Co. Galway, Co. Mayo;
(C) Southwest - Co. Cork, Co. Kerry, Co. Clare;
(D) East - Co. Louth, Co. Meath, Co. Dublin, Co. Wicklow, Co. Wexford;
(E) Southeast - Co. Cork (east); Co. Waterford.

'Survey Locations' were discrete identifiable units consisting of one or more adjacent sites (e.g. individual islands within a group) and classified by their level of potential for grey seal breeding as follows: (i) ***Category A*** – **verified sites**, from which reliable records of grey seal pups were available; (ii) ***Category B*** – sites which, based on background data and habitat features, were considered to show **high potential** for breeding activity, and (iii) ***Category C*** – sites which, based on background data and habitat features, have **limited potential** for breeding activity. Based on this design it was possible to pre-plan flights or ground survey operations according to the nature of the site being surveyed.

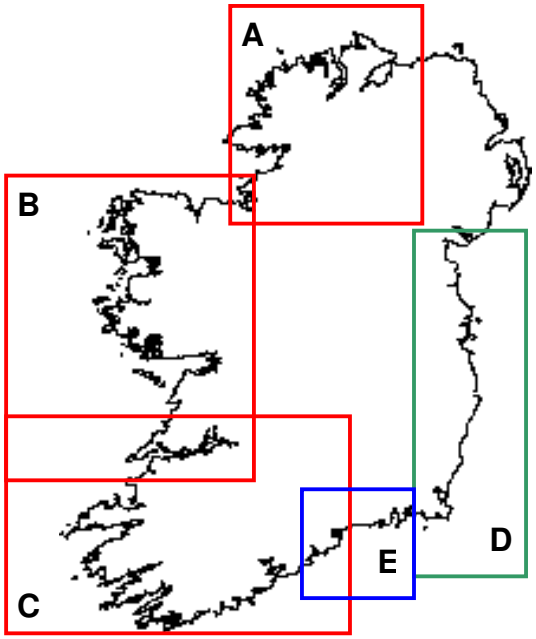


Figure 1. Map showing five search areas in the Rep. of Ireland (A-E) earmarked for survey in 2005.

Since the timing of grey seal births at a breeding colony is not synchronous, aerial or ground surveys must be carried out through the breeding season in order to estimate total pup production, and subsequently to derive an estimate of the all-age population size (*see* 2.1). The survey design developed in 2005 consisted of (i) 5-6 surveys of all Category A and B locations in each search area and (ii) at least one survey of all Category C locations when numbers of pups ashore were likely to be at their peak. Thus total pup production could be estimated for known and high-potential breeding sites and the presence or absence of significant breeding at sites of limited potential might also be established.

Due to the indented nature of the coast and pre-survey uncertainty in the time needed to survey such a substantial coastline, some overlap between search areas was incorporated (Fig. 1). Unlike the east and southeast coasts, which contained only Category A sites or sites with limited breeding potential (Cat. C), more than 25% of survey locations along the Atlantic coast were considered high potential locations. The number of these Category B sites was greatest in the west and northwest due to higher numbers of offshore islands and the presence of substantial remote mainland sites. Based on the relatively small total number of survey locations identified in search areas D and E (n=16, Appendix III), it was decided that the southeast and east coasts should be surveyed primarily using boat- and ground-based methods. Aerial surveys were thus focused among search areas A, B and C in which there was the greatest area to be covered, a higher number of sites in all categories (totals: 37, 48, 51 respectively) and more significant weather constraints to contend with.

It was not considered possible to cover all sites during the entire potential breeding season. For example, individual females may occasionally give birth considerably earlier (e.g. July) or later (January, February) than the bulk of the population, or choose atypical sites at which to pup. Also, breeding beaches within sea caves are dangerous for surveying in all but perfect sea conditions and then only by very experienced personnel.

Within these constraints, the aim of this project was to carefully consider all sites likely to contribute the vast majority of grey seal pups born nationally in the 2005 season. Where possible, sea caves were factored into the survey design.

2.5 Aerial Survey Methods

2.5.1 Flight operations

Aerial surveys carried out in the Republic of Ireland in 2005 were a combination of existing methods used in the UK (C. Duck *et al*., SMRU, *unpubl*.), methods used in an Irish research trial (Cronin *et al*., 2007b) and additional measures employed for operational and data management purposes. Following four experimental flights in order to test methodologies and familiarise survey teams with the project's requirements, the target survey period spanned the months of September to November 2005.

Plate 3. Britten-Norman *Islander* used in 2005.

Plate 4. Air Corps *Alouette* helicopter used in 2005.

A high-wing, twin-engine Britten-Norman *Islander* aircraft (Plate 3) was hired from Aer Arann Islands, Inverin, Co. Galway for 5-6 breeding season surveys in each of search areas A, B and C (i.e. along the Atlantic seaboard). Passenger windows in the front and rear of the plane were modified to include hatches for aerial photography and to provide a clearer view to the ground. A number of surveys using an *Alouette III* helicopter (Plate 4) were also planned by arrangement with the Irish Air Corps. These were aimed at sections of the west and northwest coast containing high coastal topography (>600 feet) and intricate sea cliff, gully and beach systems which, where they occur together, are very difficult to survey safely by fixed-wing aircraft due to air turbulence and limited space for manoeuvring. Thirdly, surveys of Category C locations along all coasts were to be covered via Air Corps *Cessna 172* aircraft during the expected local peak in births.

Following preliminary trials the survey altitude for breeding season surveys was set at 600-800 feet with optimal aircraft speed over ground at 70-100 knots, depending on weather conditions and the coastal terrain under survey. At this altitude and speed, adult and juvenile seals, particularly those hauled out ashore, were expected to be disturbed to some extent. Therefore the time spent surveying any breeding site was minimised as much as possible by survey design and planning. Aerial survey teams consisted of 2-3 personnel in the following roles: (i) photographer/navigator; (ii) videographer, and (iii) data-logger. Flights were planned in advance using the survey location and category

system developed in 2005. Category A locations were assigned a pattern of pre-arranged flight-paths (Fig. 2) such that (a) all-inclusive aerial images could be obtained efficiently at each site irrespective of the prevailing wind conditions and (b) images from successive surveys could be compared directly with one another, allowing for better discrimination between habitat features or the distribution of seals ashore, for example. Flight-paths could be adapted in-flight or between flights if necessary, depending on survey success and the prevailing weather conditions. Category B and C locations were assigned a flexible 'search' mode, involving observers scanning the site with the naked eye and binoculars while the aircraft passed by or circled potential breeding habitat.

2.5.2 Image capture using digital photography and videography

With the exception of sites in eastern and southeastern search areas (*see* 2.6), the estimation of grey seal pup production and breeding population size in 2005 was reliant on the use of digital aerial photography from which pup counts would be carried out in the laboratory. All Category A sites were photographed completely, covering the necessary habitats. Category B sites that were found to contain adult grey seals or pups, or were suspected to contain pups, were also photographed. Similarly, Category C sites were also photographed when appropriate.

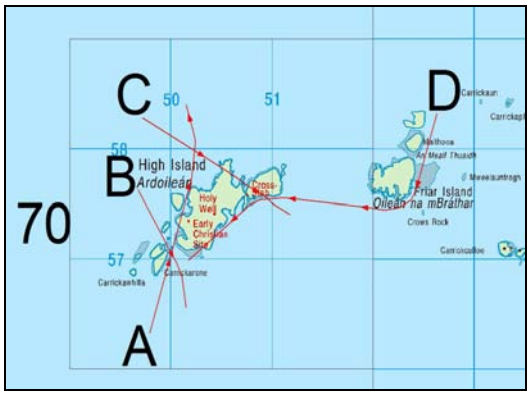


Figure 2. Four flight-paths planned for breeding season coverage of Category A Location 70.

On each aerial survey, high-resolution still photography was conducted through open hatches from the front of the *Islander* plane or from the side of the *Alouette* helicopter. Handheld digital SLR cameras (Canon™ EOS 1DS and Canon™ EOS 1D Mark II), fitted with zoom lenses (200-300mm), were used for photography. Still images were taken obliquely whether obtained from the fixed-wing plane or helicopter, while efforts were made to collect near-vertical images as much as possible to allow for better identification of living and dead pups. Image sequences and location data were logged in-flight by the data-logger and a distinct image bank was collated after each survey flight.

In addition to the primary use of still photography, a 3-CCD digital video camera (Canon™ XM2 or Sony™ TRV900) was used to collect wide-angle imagery of breeding sites (Plate 5). This method was only used in the faster-moving *Islander* aircraft, for which the rear passenger window had been fitted with a hatch. The purpose of collecting video imagery simultaneous to still photographs was to assist in site-identification; still images were taken at relatively high speed and zoomed-in, which might not provide sufficient perspective for the discrimination of similar-looking breeding beaches. To avoid blurred

video-derived stills or sequences the video camera's focus was pre-set to infinity before use. Video tapes were logged in a similar manner to digital images for later analysis.

Plate 5. Handheld video camera operation during a test survey in August 2005.

2.6. Ground Survey Methods

In parallel with the aerial survey programme, ground survey methods were employed in 2005 in order to make best use of the resources available and to enhance the quality of data gathered during the breeding population assessment as a whole. This substantial survey component was regional in emphasis (Fig. 3) and it consisted of five elements:

1. Ground- and boat-based surveys of Lambay Island and Ireland's Eye, Co. Dublin;
2. A through-counting survey of the Saltee Islands, Co. Wexford using dye-marking;
3. A land-based survey of locations along the East Cork and Waterford coasts;
4. A ground-based survey of Beginish and the Great Blasket Island, Co. Kerry;
5. Ground-truthing exercises at five regional Category A locations.

In addition to pre-survey meetings to prepare the project team for tasks relevant to each search area, a field training exercise was held in Connemara on 23-24 August 2005.

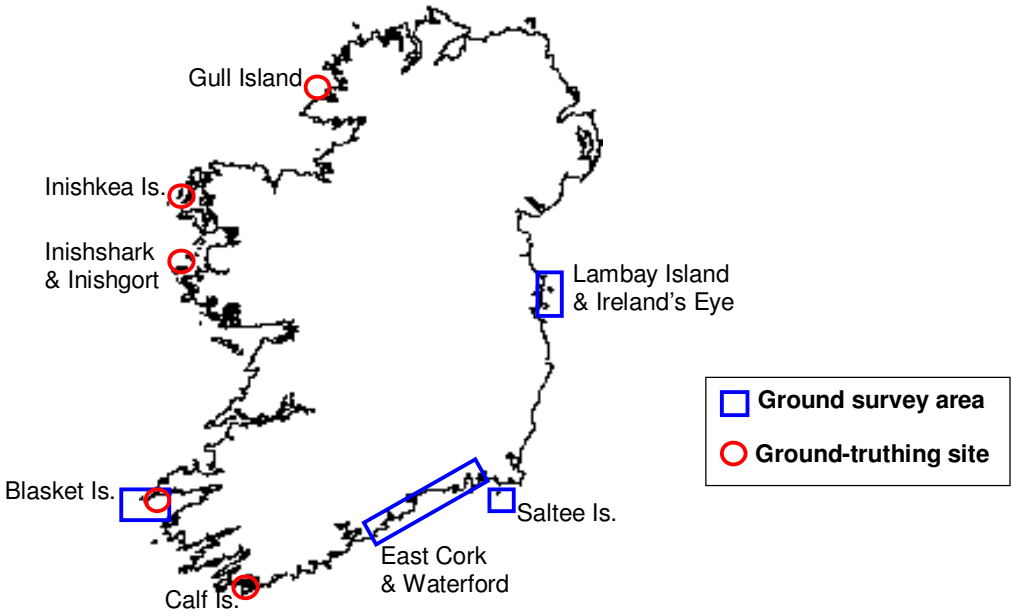


Figure 3. Colonies earmarked for ground survey effort during the 2005 breeding season.

2.6.1 Survey of Lambay Island and Ireland's Eye, Co. Dublin.

These two islands off the Co. Dublin coast were part of an extensive survey of sites for grey seals carried out along the Irish Sea and eastern Celtic Sea coasts between 1997 and 1999 (*see* Kiely *et al*., 2000; Lidgard *et al*., 2001). Experience from this earlier study, other background data, permission granted for access ashore and the availability of nearby personnel allowed survey efforts in the region in 2005 to be prioritised towards ground- and boat-based methods. After an initial visit to Lambay Island in mid-July, breeding season surveys began in late August using a hired RIB (rigid inflatable boat, Plate 6). A total of seven pup production surveys were planned at approximate 2-week intervals with all live and dead pups counted and classified by age into one of five developmental stages (Table II; *after* Radford *et al*., 1978; Kovacs & Lavigne, 1986). Dye-marking was not used. Efforts were made to place observers ashore where necessary to obtain better angles of view into partially-concealed coves, gullies and cave entrances.

Plate 6. The RIB vessel used for accessing Lambay Island and Ireland's Eye off the Dublin coast.

2.6.2 Through-counting survey of the Saltee Islands, Co. Wexford.

Surveys to estimate grey seal pup production at the Saltee Islands were carried out by through-counting in 1997 and 1998 (Lidgard *et al*., 2001) as part of the larger Irish and Celtic Sea grey seal study (Kiely *et al*., 2000). A single pup count in late September 2004 (O. Merne, *via* NPWS, *unpubl*.) suggested that higher numbers of pups might have been born than previously recorded at these islands.

In 2005, similar to the islands off Co. Dublin, the circumstances for conducting a full ground- and boat-based assessment of the Saltee Islands were favourable. It was thus decided to carry out a full dye-marking survey under NPWS licence in this case, to enable the direct comparison of pup production data between 1997/98 and the present. This would also add to knowledge of regional population status, building on repeated surveys of the Inishkea Group, Co. Mayo (Ó Cadhla & Strong, 2003) and the Blasket Islands, Co. Kerry (Cronin *et al*., 2007b).

A series of eight surveys of Great Saltee Island and Little Saltee Island were scheduled to take place at approximate 2-week intervals, beginning in the last week of August. The vessels used for access to breeding sites were a commercial passenger vessel (i.e. 'half-decker') and an NPWS *Zodiac* dinghy. The dye used for marking grey seal pups was the

standard dye solution used in other Irish through-counting studies (*see* Kiely & Myers, 1998; Lidgard *et al*., 2001; Ó Cadhla *et al*., 2005) and marking was carried out using garden sprayers (Plate 2). All pups born in 2005 were classified by age into one of five stages (*see 2.1*). Any new dead pups encountered were also recorded and marked differently to distinguish them from live-counted pups. Efforts were made to place observers ashore at all coves, gullies and cave entrances to thoroughly revisit sites surveyed in 1997 and 1998 (Lidgard *et al*., 2001).

2.6.3 Land-based survey of East Cork and Waterford.

Background research and aerial scoping surveys indicated that, while records of grey seal breeding in the region were sparse, there were ten locations within search area E (between Cork Harbour and Waterford Harbour) which should be surveyed. Three contained verified breeding sites (Cat. A) while the remainder consisted of Category C sites (i.e. limited breeding potential) including two islands, Capel Island and Ballycotton Island, Co. Cork. With the exception of sea caves, all but the islands were possible to survey on foot and it was decided that each location should be subject to survey by 1-3 personnel at least once during early to mid-October, the expected peak breeding season. The islands were earmarked for aerial survey in accordance with the survey programme established for Category C sites (*see* 2.5.1). Given the low number of historical records available from this region, any additional seal information gathered during the 2005 breeding season from members of the public, etc, was also welcome.

2.6.4 Survey of Beginish and the Great Blasket Island, Co. Kerry.

The illegal cull that occurred at the Blasket Islands during the 2004 breeding season led to an increased presence among these islands by NPWS staff in 2005. Although grey seal breeding is known to occur on several of these islands (Kiely & Myers, 1998; Cronin *et al*., 2007b), ground- and boat-based surveys in 2005 concentrated on Beginish and the Great Blasket Island, which had also been selected for ground-truthing exercises (*see* 2.6.5). Surveys on the ground would thereby include all known breeding sites involved in historic culling at these islands, a previous incident of which also occurred in 1992 (Kiely & Myers, 1998).

Plate 7. NPWS staff surveying an enclosed gully beach on the Great Blasket Island.

Methods employed at the Blasket Islands were similar to those used at Lambay Island and Ireland's Eye, Co. Dublin. After an initial scoping visit in early September, surveys continued through the breeding season using a hired RIB for boat access. Pup production surveys were planned at approximate 2-week intervals with all pups born in 2005 classified by age as above. Any dead pups encountered were also recorded. Efforts were made to place observers ashore as much as possible (Plate 7) to obtain better angles of view into partially-concealed coves and gullies.

2.6.5 Ground-truthing of aerial survey data from regional breeding colonies

Since the present study was the first nationwide population assessment of its kind for Ireland and the aerial survey methodology was being applied over a large heterogeneous coastal area it was decided early on that a representative subset of sites among known, accessible colonies should be selected for a ground-truthing experiment. These sites were intended to provide terrestrial grey seal breeding information for comparison with data gathered from the air, in addition to providing hands-on experience of grey seal population assessment for regional NPWS field staff. In investigating the accuracy of aerial and ground survey data, corrections could thus be applied to the associated pup counts if necessary.

Ground-truthing sites were pre-selected based on research knowledge, accessibility and available habitat types. The following features were considered in the selection process:

1. The known regional distribution of the grey seal population;
2. Proximity to the mainland and safe accessibility to/from the breeding colony;
3. Approximate numbers of pups likely to be produced in the season;
4. The ability of a shore observer to clearly sight and identify all grey seal pups present;
5. The presence of a range of coastal habitats on which pups could occur;
6. The availability of experienced field observers;
7. The level of human disturbance, which might impact upon pup count data.

In addition to attendance at planning meetings, ground-truthing personnel, all of whom were NPWS staff, underwent training in August while detailed maps, datasheets and guidance material were also circulated prior to commencement of the survey programme.

Three ground-truthing exercises were intended for each of five chosen breeding colonies (Fig. 5): Gull Island (Co. Donegal), the Inishkea Islands (Co. Mayo), Inishshark & Inishgort (Co. Galway), the Blasket Islands (Co. Kerry) and the Calf Islands (Co. Cork). The first exercise, a preliminary survey in early September sought to familiarise each survey team with its sites, the relevant methodology and habitats, and to resolve any operational or logistical problems encountered before the nationwide survey began. Thereafter ground-truthing sites were subject to survey on two separate occasions timed to coincide with the likely peak in pup numbers ashore while also coinciding in date with aerial surveys of each colony. Ground-truthing survey dates were separated by at least 10-15 days to minimise disturbance of adults and pups at each colony and to avoid the potential influence of human intrusion on pup count data.

In all cases except Gull Island, access to ground-truthing sites required a suitable boat. This was due to the nature of grey seal breeding in the Republic of Ireland (*see* 1.1) and also to the necessity for sufficient numbers of pups across a range of habitat types, by

which meaningful comparisons might be made between aerial- and ground-acquired pup data. Given these criteria, an intended sample size of 26 distinct ground-truthing counts was set, i.e. two counts at 13 defined sites among five breeding colonies. Habitats covered included grass/dune systems, rock pools and ledges, boulder beach, stone and sand beaches, narrow gullies and sites with overhanging cliffs (Plate 7).

2.7 Data Analysis

2.7.1 Image analysis in 2006

On completion of the aerial survey programme in December 2005, all digital still images were arranged within the assembled image bank for analysis. These images were then viewed on flatscreen computer displays using image handling software that allowed for adjustments to zoom, exposure, sharpness and image resolution. Data for each aerial survey and its associated imagery were logged using a standard recording format. Duplicate images for the same site on the same survey day were noted, as was the individual quality of each still image to be viewed. Images considered too poor in quality (e.g. too dark or blurred) were discarded from further analysis. Digital video tapes were compiled and viewed initially by direct connection with a colour monitor or PC display. If required for determining the geographic position of a specific segment of coastal habitat the relevant digital tape was reviewed alongside the corresponding still image sequence.

2.7.2. Counting grey seal pups from aerial imagery

During the image analysis process, two researchers scanned all still images for the presence of living and dead grey seal pups. Detailed analysis was first preceded by a familiarisation period for both researchers during which they became fully familiar with software and image features, and with the optimal method for performing pup counts.

A procedure was established whereby each set of images and each image within the set was worked through in a coherent pattern, allowing for site overlap if necessary using identifiable features on adjacent frames. This standard procedure was necessary to avoid confusion or repeated scans of imagery when using such a large amassed image bank. Building on the experience of previous Irish surveys (D. Strong & G. O'Donnell, NPWS, *unpubl.*; Ó Cadhla *et al.*, 2006; Cronin *et al.*, 2007b) and pre-survey trials, a protocol for identification of grey seal pups on all habitat types was also established, factoring in all recognisable cues (e.g. flippers, eye sockets) and possible sources of error in counting (e.g. pups in water or juvenile seals).

Dead pups (Plate 8) were identified as such by their unusual posture, emaciated condition, the presence of large open wounds or empty eye sockets, and their continued position and physical deterioration on images from successive survey dates. Where an object appeared to resemble a grey seal pup but sufficient determining cues were not available to the viewer the item was noted and subsequently reviewed by both analysts before being discounted. Strict adherence to the identification protocol was necessary to avoid the inclusion in pup counts of various other items (e.g. boulders, buoys, plastic containers) that, depending on their shape, substrate and lighting conditions can resemble seal pups.

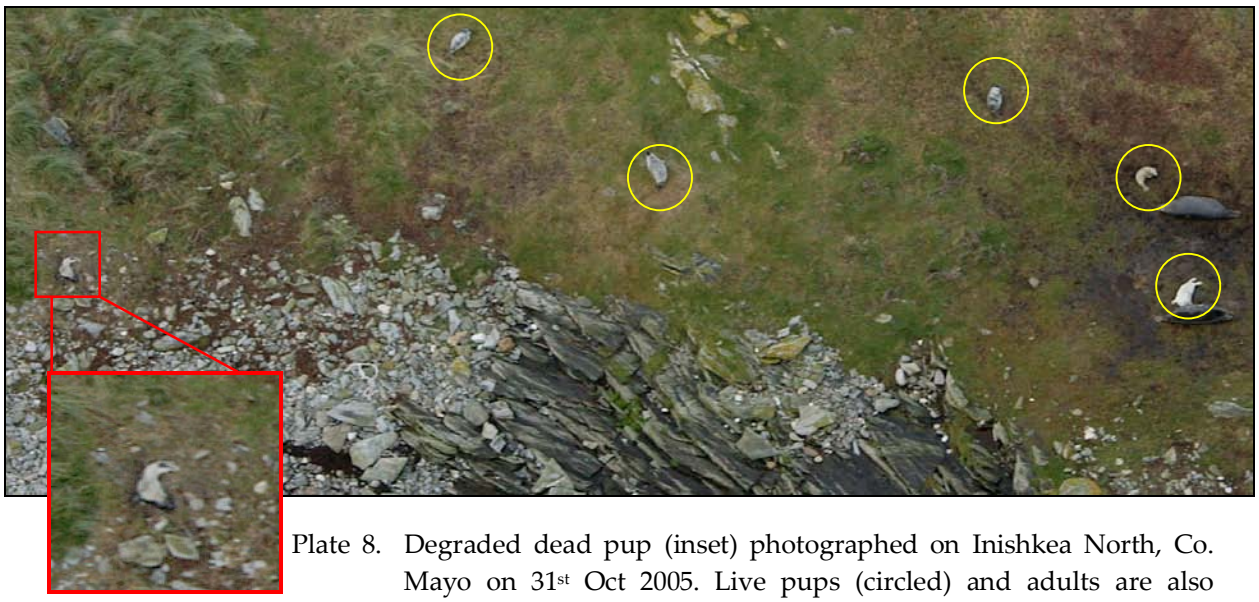


Plate 8. Degraded dead pup (inset) photographed on Inishkea North, Co. Mayo on 31st Oct 2005. Live pups (circled) and adults are also shown. [Inset magnification = 3x].

Where grey seal pups were positively identified from the still imagery, each pup's approximate developmental stage (Stage I → Stage V) was recorded along with its site and associated habitat information (*after* Fossitt, 2000). Pups recorded in narrow gullies, caves or in water were specifically documented to assess whether pup detectability was affected by such features. Each survey's pup count data were compiled into spreadsheets and summarised for further analysis. The maximum number of grey seal pups observed on a single survey delivered a crude minimum pup count for each survey location (Appendix III). Its date also gave an indication of the timing of peak births within the breeding season. More accurate, however, were data delivered by the incorporation of pup counts from all survey dates into a statistical analysis of pup production (*see* 2.7.5).

2.7.3 Comparison between aerial- and ground-acquired pup counts

Once the process of recording live and dead pups from all aerial survey imagery was complete, counts were performed using imagery acquired from the 13 predefined ground-truthing sites only. These were done "blind", i.e. without knowledge of the ground-truth data for each specific site. Aerial and ground count figures were then compared to assess the accuracy of the aerial technique in determining the correct pup counts and pup stages. Where significant discrepancies occurred, ground survey teams were consulted and reviews of both aerial- and ground-acquired data were carried out. If necessary a correction factor, to take account of the discrepancy, could be considered as a potential solution.

2.7.4. Analysis of ground survey data – East and southeast coasts

All pup production data gathered among sites off Co's. Dublin, Cork and Waterford were in the form of ground counts of living and dead pups. Since dye-marking had not been used in these cases, it was not possible to reliably discriminate between individual pups born and recounted on successive surveys. In this manner ground count data gathered from these areas resembled the aerial pup count data. Thus they underwent the same statistical analysis for estimating total pup production (*see* 2.7.5).

Surveys over the 2005 season at the Saltee Islands, Co. Wexford did involve the dye-

marking of pups. Thus two types of analysis were performed on the Saltee Is. dataset:

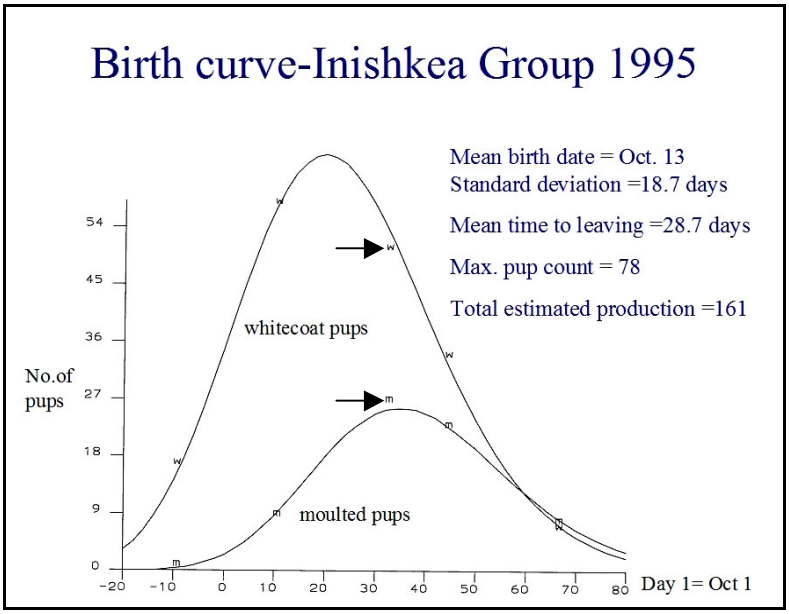
1. On through-count data to compare the observed pup productions in 1998 and 2005;
2. Pup production modelling as conducted with the new Irish pup count data. (*see* 2.7.5)

Permission for the re-use of through-count data gathered in an earlier study along the east and southeast coasts of Ireland (Kiely *et al*., 2000) was kindly provided by D.C. Lidgard and co-authors (*see* Lidgard *et al*., 2001). These data were used in plots to directly compare pup counts at the Saltee Islands over each of the 1998 and 2005 breeding seasons and furthermore, to model pup data from the key eastern and southeastern breeding colonies in 1998, bringing the results into line with statistical analysis of the 2005 data (*see* 2.7.6).

2.7.5 *Estimating pup production and population size*

Overall estimation of grey seal population size was firstly reliant on pup production data from all of the above sources. Staged pup counts from aerial survey imagery, ground- and boat-based surveys formed a production spreadsheet for each survey location. If necessary, a correction to aerial survey pup count data was envisaged to account for the results of ground-truthing. The estimation of total pup production at each survey location, and so in the Republic of Ireland as a whole, then depended on modelling the observed birth rate against an established statistical framework that describes how the numbers of pups vary over the season (Fig. 4; Hiby *et al*., 1988; Myers *et al*., 1997).

The production estimation model (*PEST*) designed for this process was developed by A.R. Hiby (Conservation Research Ltd., UK) and SMRU where it has been used for UK grey seal pup production estimation since 1984 (C. Duck *et al*., SMRU, *unpubl*.). Previously used to simulate and derive estimates of pup production at two Irish breeding colonies (Kiely *et al*., 1997 – Fig. 4; Cronin *et al*., 2007b), the *PEST* model allows various parameters (e.g. degree of pup misclassification, time to moulting, time to leaving the breeding site) to be fixed or freed in order to deliver the most accurate model fit to the observed counts, thereby reducing the error (i.e. coefficient of variation or CV) of each production estimate.



(*from* Kiely *et al*., 1997)

Figure 4. Example of *PEST* model output showing sample pup datapoints (arrows) and the maximum likelihood best fit to the data points (smooth lines).

Once the statistical analysis for all 2005 data was completed and total production estimates were available for each breeding colony, ancillary pup count data were added from Category C sites, which had been surveyed at least once as close to the expected local peak in births as possible (*see* 2.5.1). Total pup production estimates were then subject to multiplication by a factor of 3.5-4.5, representing the ratio of newborn pups to an increasing all-age population (Harwood & Prime, 1978). This has been the standard method applied previously in Ireland, given the absence of additional life history data and the lack of a time-series of pup production estimates from the key breeding colonies (e.g. Inishkea Group, Ó Cadhla & Strong, 2003).

Pup production results from the 2005 survey programme and estimates of all-age population size were displayed using *ArcView* GIS (Geographical Information System) software. This enables the incorporation of new or historic survey data in successive data layers, providing an appropriate framework for the analysis and presentation of data from ongoing national monitoring effort. In mapping survey locations and discrete sites or areas within those locations, positional data were given for the approximate centre-point of each, whether an individual island or stretch of surveyed coastline (e.g. Appendix III).

2.7.6 Investigation of changes in pup production: 1995-2005

In order to robustly evaluate potential changes in population status at better-studied breeding colonies, it was decided that pup count data gathered by boat- and ground-based surveys between 1995 and 2004 should also be integrated statistically using the *PEST* model. In this manner total pup production estimates and population estimates could be compared for a range of colonies and years. In addition to the Saltee Islands (*see* 2.7.4) the data used by permission in these model analyses were as follows:

Table III. Research data from 1995-2004 that were used to investigate population changes.

COUNTY	BREEDING COLONIES	YEARS	DATA TYPE	SOURCES
Mayo	Inishkea Group	1995	Pup through-count	Kiely & Myers, 1998
		2002	Pup through-count	Ó Cadhla & Strong, 2003
Kerry	Blasket Islands	1996	Pup through-count	Kiely & Myers, 1998
		2003	Aerial survey pup count	Cronin & Ó Cadhla, 2004 Cronin *et al*., 2007b
Wexford	Saltee Islands	1998	Pup through-count	Lidgard *et al*., 2001
Dublin	Lambay Island & Ireland's Eye	1998	Pup through-count	Lidgard *et al*., 2001
Galway	Ferroon Rocks & Illaunamid (Slyne Head islands)	2004	Pup through-count	Ó Cadhla *et al*., 2005

3. RESULTS

3.1 Survey Outcomes

3.1.1 Overview

The 2005 grey seal population assessment was considered a success, both operationally and methodologically. While working around prevailing weather conditions, the survey design allowed all Category A (i.e. known breeding), Category B (i.e. high potential for breeding) and Category C (i.e. limited potential) locations to be surveyed as planned whether by air or on the ground. The overall survey programme thus yielded the following crucial results:

- A total of **1,574 grey seal pups** was estimated to have been born in the Republic of Ireland during the 2005 breeding season. (*see* 3.3)
- The derived population estimate for the Republic of Ireland in 2005 was **5,509—7,083 grey seals of all ages**. (*see* 3.4)

3.1.2 Aerial surveys achieved

Following trial flights, weather conditions allowed full surveys of search areas A, B and C (Fig. 1) to begin by the 10th September. These continued until 6th December, delivering a minimum of 5-6 survey visits to every Category A and B location, with the exception of Sauce Creek, Co. Kerry (Loc. 44, n=4) and Tory Island, Co. Donegal (Locs. 117-118, n=4) (Appendix III). Surveys of Category C locations were incorporated in October and November with each location surveyed at least once (*see* 2.5.1). The result was an intensive survey programme of 34 flights (Fig. 5).

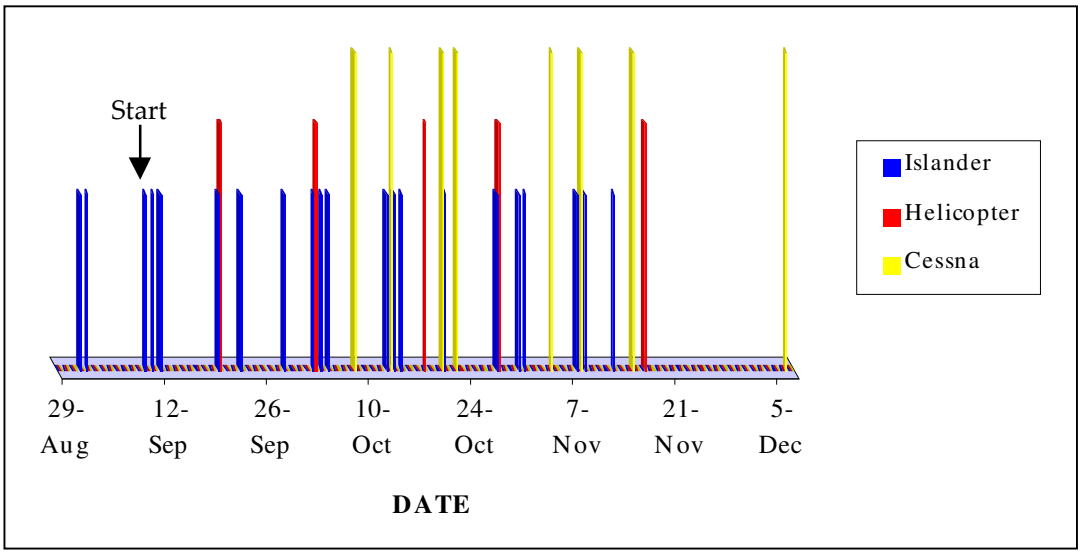


Figure 5. Aerial survey schedule achieved during the 2005 breeding season, via a range of aircraft.

Survey altitudes and speeds were generally as intended, though exceptions were required in some local circumstances due to excessive wind turbulence experienced in the *Islander* (e.g. along the north coast of Donegal). On such occasions the survey altitude was generally adjusted upwards to between c. 1,000 and 1,200 feet. On one occasion, a back-up

aerial survey of the Blasket Islands was required in better wind conditions to be certain that good quality imagery had been gathered. In the case of Sauce Creek, persistent turbulence made it difficult to survey well by air. A single back-up survey of the north Donegal coast (i.e. Inishowen peninsula) was also carried out by boat, to confirm data being gathered by air along this turbulence-prone coastline. The availability and use of an Air Corps helicopter reduced the need for such measures and proved essential in dealing with key sections of complex high coastal topography along the west and northwest coasts in particular.

The use of pre-arranged flight-paths proved worthwhile, with adjustments performed as required on each survey day depending on the weather conditions. For example, in the southwestern region (search area C) conditions frequently allowed smaller islets to be surveyed by circling instead of using straighter flight-paths, thereby saving flying-time. Such adjustments were less feasible along the western and northern seaboards due to stronger prevailing wind conditions.

3.1.3 Image analysis

A total of 16,861 still images and 12 digital video tapes (max. duration: 60') were recorded during the aerial survey programme. The analysis of the assembled image bank (*see* 2.7.1, 2.7.2) took place between January and October 2006. Following initial examination, which included the identification of duplicate still images and those where image quality was too poor for use (<2%), the working library of still images obtained from each search area was as follows:

- Search Area A – Northwest: 5,735
- Search Area B – West 7,444
- Search Area C – Southwest 3,155
- Search Area D – East 274

16,608 in total

The process resulted in 3,062 records of living and dead grey seal pups. Many surviving individual pups were likely to have been photographed more than once due to the target 2-week intervals between surveys. Of the total, 178 records (5.81%) were of pups detected while swimming in shallow inshore waters (Plate 9) or ashore in pools. A further 67 pups were recorded occurring in small caves (Plate 10) or within the entrances to larger caves.

Plate 9. Whitecoat pup (arrow) in the water (2x).

Plate 10. Pups (circled) and adults in a cave.

In some cases, manipulation of brightness and contrast settings for individual images allowed pups to be detected even though they were well under overhanging cliffs. A total of 43 pups recorded from the aerial imagery were defined as dead pups, based on analyst evaluation and the protocol used in the identification process (*see* 2.7.2). While c. 65% of these records (n=28) were obtained from sites along the west coast (Search area B, Fig. 1), the proportion of 'dead pups to total pups' recorded in the image bank was highest for search area A (NW – 1.81%) followed by search areas B (W - 1.52%) and C (SW – 0.55%).

3.1.4 Ground survey results

Good sea conditions permitted site visits by ground survey teams (Appendix II) to begin by the end of August. These continued into December, resulting in a total of 40 surveys (Fig. 6). Most frequently surveyed were the Blasket Islands (n=8), due to ongoing conservation concerns after the illegal cull in 2004. Seven full surveys were conducted at the Saltee Islands, Lambay Island and Ireland's Eye in search area D, while ground-truthing surveys were carried out as planned at five colonies (Fig. 3).

(i) Lambay Island & Ireland's Eye: Surveys were carried out among these islands at regular intervals of 11-16 days (Fig. 6), beginning on 30th August. The combination of boat-based and ground-based survey effort worked well together. The first pups of the season were recorded on 13th September, reaching a peak total count of 52 on 13th October and declining thereafter to two pups on 22nd November.

Pup production occurred predominantly on Lambay Island with only four pup records from Ireland's Eye during the 2005 season. No dead pups were recorded on either island. The distribution of pupping on Lambay Island was strongly aggregated among three 'bays' on the south coast. Previously-documented cave sites on either island were not entered by the survey team for safety reasons. Consequently pup production estimates derived for these islands were expected to be slightly lower than the true figure.

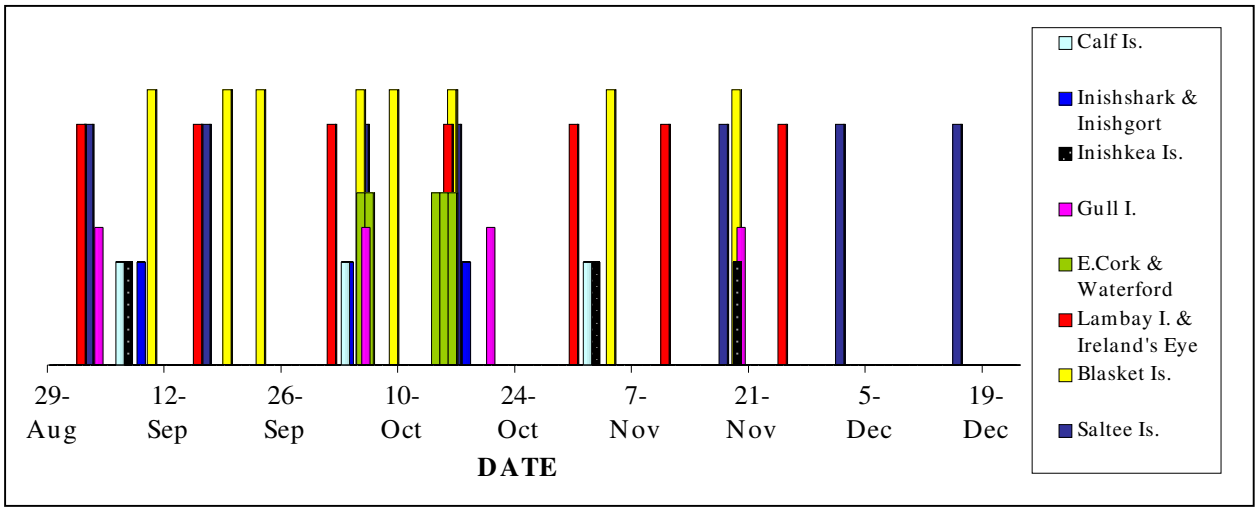


Figure 6. Ground survey effort carried out in the Rep. of Ireland during the 2005 grey seal breeding season. Locations are shown in order of increasing survey frequency.

(ii) Saltee Islands: Through-counting surveys began on 30th August with three pups recorded and dye-marked on this date, one of which was over three weeks old. Surveys were attempted thereafter at intervals of 10-15 days and this target was met on four occasions. However persistently poor sea conditions, to which the Saltee Islands are exposed, occurred in mid- to late September and again from mid-October to mid-November. This resulted in survey intervals of 21 days and 32 days respectively. In anticipation of difficulties with data continuity into November, a single back-up aerial survey of the islands was conducted with the Air Corps on 8th November.

Boat-based and ground-based survey effort yielded a peak total count of 113 pups on 2nd October, declining thereafter to one new pup on 28th November and 12th December consecutively. Pupping occurred predominantly on the Great Saltee (n=174) with only four pup records from the Little Saltee during the 2005 season. A total of four dead pups (2.25% of total production) was recorded, all of which were discovered on the Great Saltee.

A very broad distribution of pupping was observed on this larger island, encompassing boulder beaches, narrow coves and caves on the island's southeast-facing flank and the extensive, sheltered boulder beach on the north coast (Plate 11), stretching approximately 1.5km long. It appeared that the north coast was favoured as the season progressed. Cave sites on the Great Saltee (none occur on the Little Saltee) were entered by the survey team when possible. Thus pup production estimates delivered by through-counting in 2005 were expected to be relatively accurate and comparable to surveys carried out in 1997/98.

Plate 11. Aerial photograph taken from an Air Corps *Cessna 172* on 8th November 2005, showing the main landing area on the north of the Great Saltee Island with grey seal adults hauled out on sand and in the water.

(iii) East Cork & Waterford: A series of five ground surveys, collectively covering almost the entire coastline between Cork Harbour and Waterford Harbour (i.e. search area E), was completed in early-mid October (Fig. 6). Weather conditions were good during each of these cliff-top surveys and all designated survey locations (Appendix III: 1-3, 142-148) were included in the ground survey programme. No pups were recorded and just 3 adult grey seals were seen by the observers during the five-day period. These were recorded along the Co. Waterford coast, one animal entering a cave at Ardoginna (Location 148).

Additional information gathered in the area by the survey team and reliable second-hand reports recorded occasional sightings of individual grey seals along the East Cork and Waterford coasts between September and November. Three of the eight records received were of dead adults, a fourth was a dead juvenile. No second-hand reports of pups were received by members of the survey team.

(iv) Beginish & Great Blasket I: Six surveys were conducted prior to and during the expected peak in births at the Blasket Islands at intervals of 4-12 days (Fig. 6), beginning on 7th September (Fig. 6). On this date nine pups were recorded, all on Beginish. Ground surveys concentrated on this and the Great Blasket Island and a peak in numbers was recorded on the 13th October. Pups were also recorded on nearby Illaunbwee (Oileán Buí) and Carrigadda (An Charraig Fhada) and the more distant Inishvickillane (Inis Mhic Aoibhleáin) when visited once on 16th September.

Two surveys took place in November, the latter survey (16/11/05) continuing to record over 75 pups ashore on Beginish and the Great Blasket combined. Within these two islands, newborn pups were found on all previously-described breeding sites (*see* Kiely & Myers, 1998) during the course of the season, including beaches on which illegal culling was carried out in 2004. Three dead pups were recorded in total during the eight survey visits in 2005, two on the Great Blasket and one on Beginish.

Pup records obtained were used primarily for ground-truthing purposes (*see below*) since pup production estimates for the Blasket Islands as a whole relied on the full inclusion of other islands in the group and aerial survey data could be directly compared with similar survey effort in 2003 (Cronin *et al*., 2007b), before the illegal cull in 2004.

3.2 Ground-truthing of Aerial Survey Data

All sites earmarked for ground-truthing were visited at least three times during the 2005 breeding season with two sample counts delivered for comparison with aerial survey data. Surveys were occasionally difficult to synchronise with the day of, or day after, each

aerial survey due to prevailing sea conditions and variation in the availability of boats and personnel on the day. Of 26 ground survey replicates (Table IV) eight dates (30.8%) matched those on which aerial surveys were performed and sixteen (61.5%) took place within two days of one another. The remaining two comparative surveys were separated by a period of four days (Calf Islands, Table IV).

Table IV. Test data used to compare the accuracy of aerial- and ground-derived pup counts.

LOCATION	SITE	Aerial data *Test A*	Ground data *Test A*	Aerial data *Test B*	Ground data *Test B*	Aerial–Ground *A*	*B*
Calf Islands	A	3 Oct – 2 pups	3 Oct – 3 pups	28 Oct – 13 pups	1 Nov – 12 pups	-1	+1
	B	3 Oct – 0 pups	3 Oct – 0 pups	28 Oct – 0 pups	1 Nov – 0 pups	0	0
Beginish [a]	A	20 Sept – 10 pups	20 Sept – 12 pups	13 Oct – 28 pups	13 Oct – void	-2	void
	B	20 Sept – 0 pups	20 Sept – 0 pups	13 Oct – 27 pups	13 Oct – 28 pups	0	-1
Great Blasket I.[b]	C	20 Sept – 0 pups	20 Sept – 0 pups	13 Oct – 9 pups	13 Oct – 13 pups	0	-4
Inishshark [c]	A	5 Oct – 33 pups	3 Oct – 44 pups	15 Oct – 31 pups	17 Oct – 31 pups	-11	0
	B	5 Oct – 19 pups	3 Oct – 19 pups	15 Oct – 28 pups	17 Oct – 29 pups	0	-1
Inishgort [d]	C	5 Oct – 18 pups	3 Oct – 31 pups	15 Oct – 22 pups	17 Oct – 31 pups	-13	-9
	D	5 Oct – 3 pups	3 Oct – 2 pups	15 Oct – 0 pups	17 Oct – 2 pups	+1	-2
Inishkea North [e]	A	31 Oct – 48 pups	1 Nov – 42 pups	17 Nov – 34 pups	18 Nov – 32 pups	+6	+2
Inishkea South	B	31 Oct – 44 pups	1 Nov – 43 pups	17 Nov – 28 pups	18 Nov – 28 pups	+1	0
	C	31 Oct – 15 pups	1 Nov – 13 pups	17 Nov – 3 pups	18 Nov – 0 pups	+2	+3
Gull Island	A	18 Oct – 39 pups	19 Oct – 41 pups	17 Nov – 8 pups	18 Nov – 7 pups	-2	+1

Although a comparatively small sample size was available (n=25, Table IV), and changes in pup distribution and numbers could occur between survey dates, the ground-truthing exercise and its analysis yielded a number of key results:

1. On sampling occasions when no grey seal pups were recorded on the ground, independent data from aerial imagery concurred with these findings;

2. Among ground-truthing sites as a whole, aerial imagery may have very slightly under-recorded the number of pups present (median difference = 0; mean & s.d.= -1.304 ± 4.363; n=25);

3. However no significant difference was detected between pup numbers recorded from the ground and from the air (T=148, 18 d.f., P>0.1, Wilcoxon test for matched pairs);

4. 76% of aerial count—ground count records were within ±2 pups of one another;

5. The degree of difference between counts did not show a relationship with the total number of pups at the ground-truthing site (i.e. observed differences were not density-dependent) (Fig. 7).

6. Records of dead pups (Plate 12) from ground and aerial counts agreed closely with one another (92.0% within ±1 pup) and anomalies occurred only at site C on Inishgort (*see above*);

7. Differences between ground counts and aerial counts of ±4 and greater could be explained, at least in part, by site topography, variation in ground survey methodology and the movement of pups from designated ground-truthing areas (*see [a-e] below*).

8. Based on the information available, and allowances for small changes in pup counts at a site from day to day, it was decided that the data obtained from aerial imagery in 2005 should not be subject to a correction factor prior to further analysis (*see* 3.3).

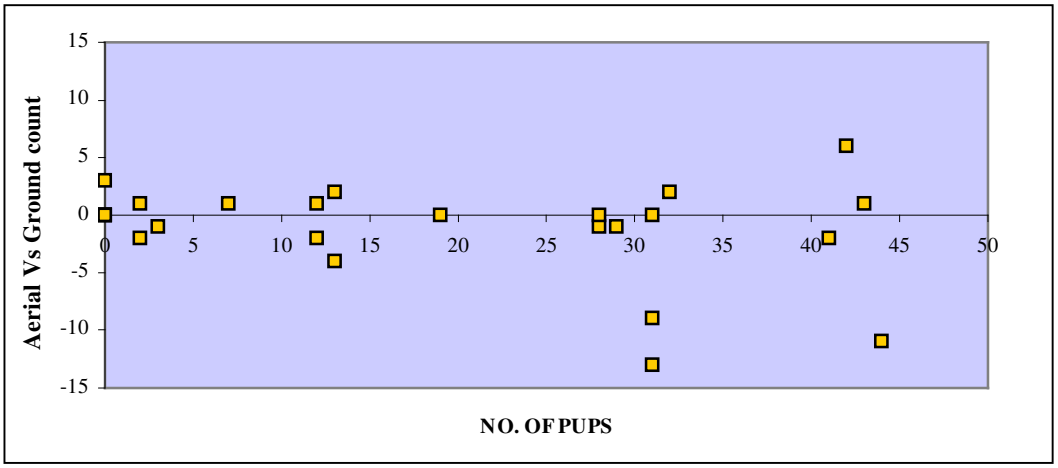


Figure 7. Comparison between pup counts derived from aerial imagery and those from each corresponding ground-truthing test (i.e. aerial-count minus ground-count), with respect to the total number at each test site.

[a] Beginish: One replicate was unavailable for comparison since the ground count included an unknown number of pups from outside the designated survey Site A.

[b] Great Blasket I: Site C contained three enclosed gullies, with narrow entrances and tall bordering cliff-faces (Plate 7). Such sites are difficult to survey completely from the air or land and incur the risk of missing individual pups, as was shown here.

[c] Inishshark: Site A was an area containing two enclosed gullies backed by steep cliff-faces. Some pups present in both gullies on 3rd October were not on aerial imagery taken on the 5th. Careful re-evaluation of the imagery suggest that the available area was not fully covered, which may explain the discrepancy on this date.

[d] Inishgort: Defining the exact limits of Site C, an area of mixed beach and rocky habitat, proved difficult. Re-evaluation of aerial imagery indicated it likely that extra pup records were included in the ground count data from this site. The site is surveyed relatively easily by air and on the ground.

[e] Inishkea North: The cause of the difference between 31st October and 1st November is unclear. Five pups were recorded in the water on 31st October and may have moved outside the specific limits of the site.

Plate 12. A dead grey seal pup recorded on a breeding island off northwest Co. Galway.

3.3 Breeding Distribution and Pup Production Estimates

Once the analysis of aerial imagery had been completed in October 2006, the collation information from all sources drove a numerical assessment of the Republic of Ireland's grey seal breeding population. Pup production, mean birth-dates and a selection of data are given in Appendix III.

The distribution of sites containing pups between August and December 2005 showed that all coastlines were used by breeding grey seals with a particular spread in pup distribution along the west and northwest coasts and significant gaps in distribution along parts of the south, southwest and mid-west coasts (Fig. 8). The absence of breeding records along much of the east coast could be explained by the lack of potential breeding habitat along a large portion of this coastline.

Grey seal pups were present at 41.2% of the survey locations covered by the survey programme (n=61 out of 148), where features such as background data, habitat availability and isolation indicated the potential for grey seal breeding. Of 72 sites for which verified breeding records were available pre-survey (i.e. Category A sites), eighteen (25%) were not found to contain pups in 2005. In contrast, a total of 30 new sites were discovered with pups ashore: 21 high potential (Category B) sites and nine limited potential (Category C) sites. The data indicate that most newly recorded sites saw less than 10 pups born over the course of the breeding season. However newly recorded breeding sites on the offshore islands of Croaghnakeela Island (Co. Galway), Ardboline (Co. Sligo), Rathlin O'Birne Island and Aran Island (Co. Donegal) and along cliff-bound sections coast of the north Mayo and southwest Donegal coast contained higher pup totals (Appendix III).

The pup production estimation process, based on aerial and ground count records of living and dead pups, delivered satisfactory results. In spite of occasionally small numbers of pups recorded on individual survey flights or ground visits (in the case of Locations 134, 135 & 140), pup count data were modelled quite accurately using the production estimation model. This was done by setting a minimum target of 20-30 pups per estimation unit whereby count data from adjacent sites that contained comparatively low totals were grouped together to exceed the 20-pup threshold and the data modelled

thereafter to obtain a collective production estimate (P_g, Appendix III). This procedure was possible for all data with exception of counts from Category C sites and those from north Donegal (Locations 115-132) where pup figures from aerial survey imagery were markedly low.

Model runs were conducted assuming (i) a normal, and (ii) lognormal distribution of births over the course of the breeding season. Using a normal birth-distribution curve, rather than a lognormal birth-curve plot, tended to deliver lower, more stable, coefficients of variation (CVs) for each estimate unit. Experimental tests with model settings for variables such as the time taken for new pups to fully moult or leave, or the percentage of pups misclassified as whitecoat/moulted, pointed towards the use of standard model settings for the UK, since CVs tended to increase with each test modification.

Allowing a 5% loss/non-detectability of pups due to mortality and other factors, a series of 26 pup production estimates was derived for individual (P_i) and grouped (P_g) breeding sites (Appendix III), assuming a normal distribution of births over the season. By summing the appropriate pup production estimates (P_i or P_g) with count data from all Category C sites and sites in north Donegal, a national minimum production estimate was obtained:

Republic of Ireland grey seal pup production estimate, 2005 = 1,574 pups

Approximately 84% of the recorded pup production in 2005 occurred in seven breeding colonies or relatively discrete breeding areas (Table V). Five are situated along the Atlantic seaboard of Ireland, one in the northeastern Celtic Sea and one in the western Irish Sea. Although ground-based pup count figures have been obtained at most of these colonies at least once since 1995 (Table I), the new data acquired for islands in northwest Galway (including Inishshark and Inishgort, Plate 13) and an extensive isolated mainland area of southwest Donegal delivered a very significant 29.4% of the national figure. Southwestern Donegal also delivered an unexpected result in the timing of grey seal births with the mean birth date calculated to occur between the 23rd and 25th September (Table V), earlier than expected based on data from previously-studied breeding colonies along the west coast.

Plate 13. Image of Inishgort off northwest Co. Galway, a breeding island of national significance.

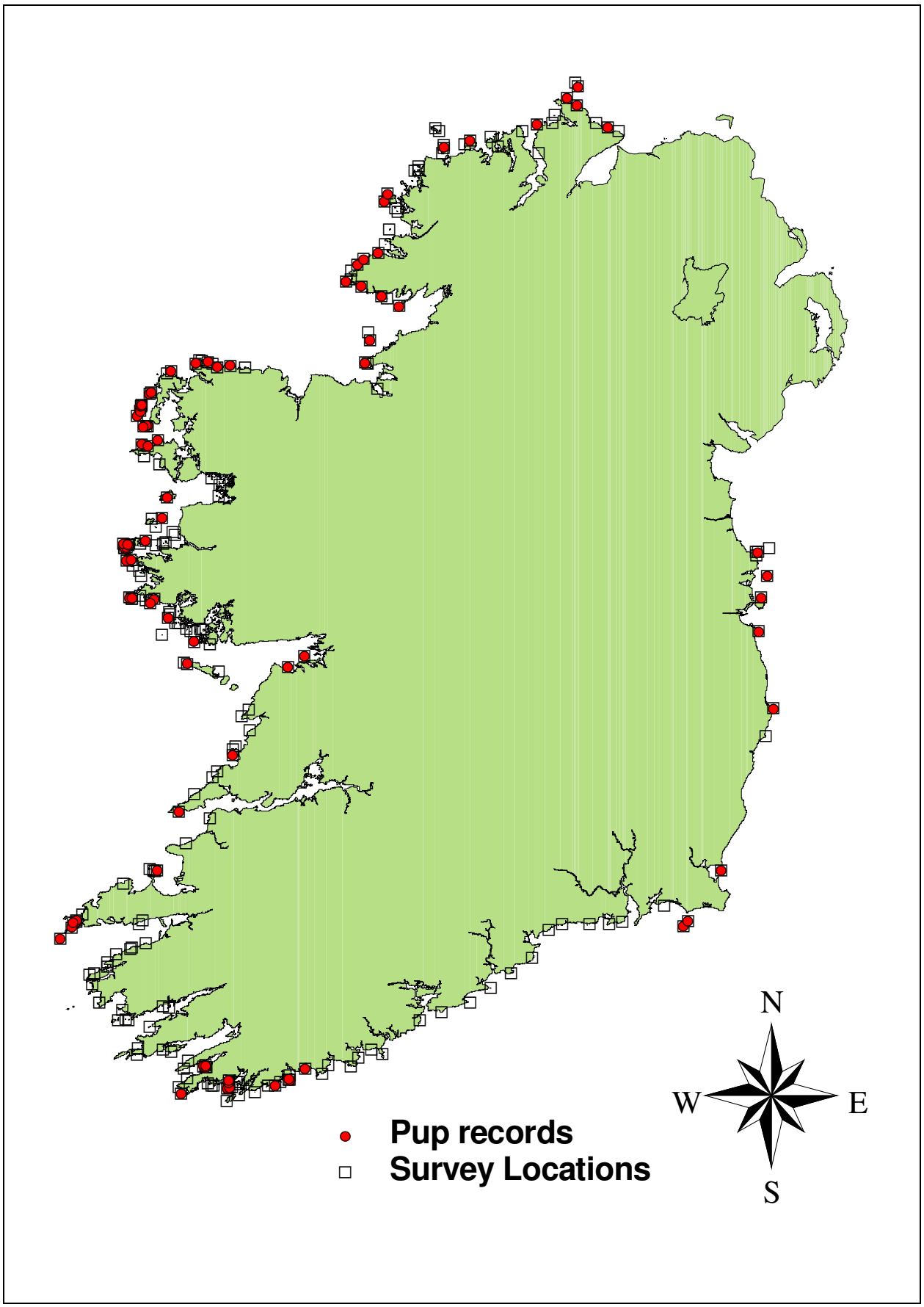


Figure 8. The distribution of grey seal pup records among 148 survey locations covered in the Republic of Ireland between August and December 2005. Locations are plotted as the centre points assigned to sites among all survey categories (A, B and C).

Table V. Pup production and population estimates from the seven most important grey seal breeding areas in the Republic of Ireland, 2005. Production figures (P) represent the combined totals from individual survey locations in each breeding area.

COUNTY	BREEDING AREA	Survey Locations	Minimum Pup Production (P)	Mean birth date	All-age population size
Mayo	Inishkea Group	87–89	386 pups	27 Sept to 13 Oct	1,351 – 1,737
Galway	Northwest Galway islands	70–73	235 pups	5-7 October	823 – 1,058
Donegal	Sturrall to Maghera	108–109	227 pups	23-25 September	795 – 1,022
Kerry	Blasket Islands	41–42	185 pups	7 October	648 – 833
Wexford	Saltee Islands	140	163 pups	21 September	571 – 734
Galway	Slyne Head islands	68	68 pups	16 October	238 – 306
Dublin	Lambay Island & Ireland's Eye	134–135	58 pups	25 September	203 – 261

3.4 All-Age Population Size in 2005

Based on pup production data obtained by means of aerial survey imagery, ground counts and statistical modelling, estimates of total and regional population size were calculable using a 3.5-4.5 pup:all-age multiplier (*after* Harwood & Prime, 1978). Results for the Republic of Ireland are displayed graphically (Fig. 9), taking account of the need to pool pup count data in some cases where production at individual sites was comparatively low (Appendix III; *see* 3.3). The resultant all-age national population estimate delivered by the survey programme was as follows:

Republic of Ireland all-age population estimate, 2005 = 5,509 – 7,083 grey seals

Over half of the national population recorded in 2005 (i.e. 50.8%) was associated with breeding sites located in Counties Mayo and Galway, the largest breeding area in the Republic of Ireland being the Inishkea Group, Co. Mayo (Table V). Other important regional colonies (>150 grey seals) were centred in southwest Donegal, the Blasket Islands, the Saltee Islands, Lambay Island and west Cork (Fig. 9; Table V; Appendix III).

3.5 Changes in Pup Production: 1995 to 2005

Modelling of datasets gathered between 1995 and 2004, assuming normal distribution of births over the season, indicated that production at the majority of colonies was larger in 2005 than recorded in previous years (Appendix IV). Similar to model runs of data from 2005, normal distribution plots tended to deliver lower coefficients of variation (CVs) than the corresponding lognormal plots. CVs were notably higher overall from datasets gathered in 1995, 1996 and 1998 than in years since 2000. One sample breeding colony did not show an increase between survey years - the Slyne Head group of islands, which gave the same estimate from through-count data gathered in 2004 and aerial count data in 2005.

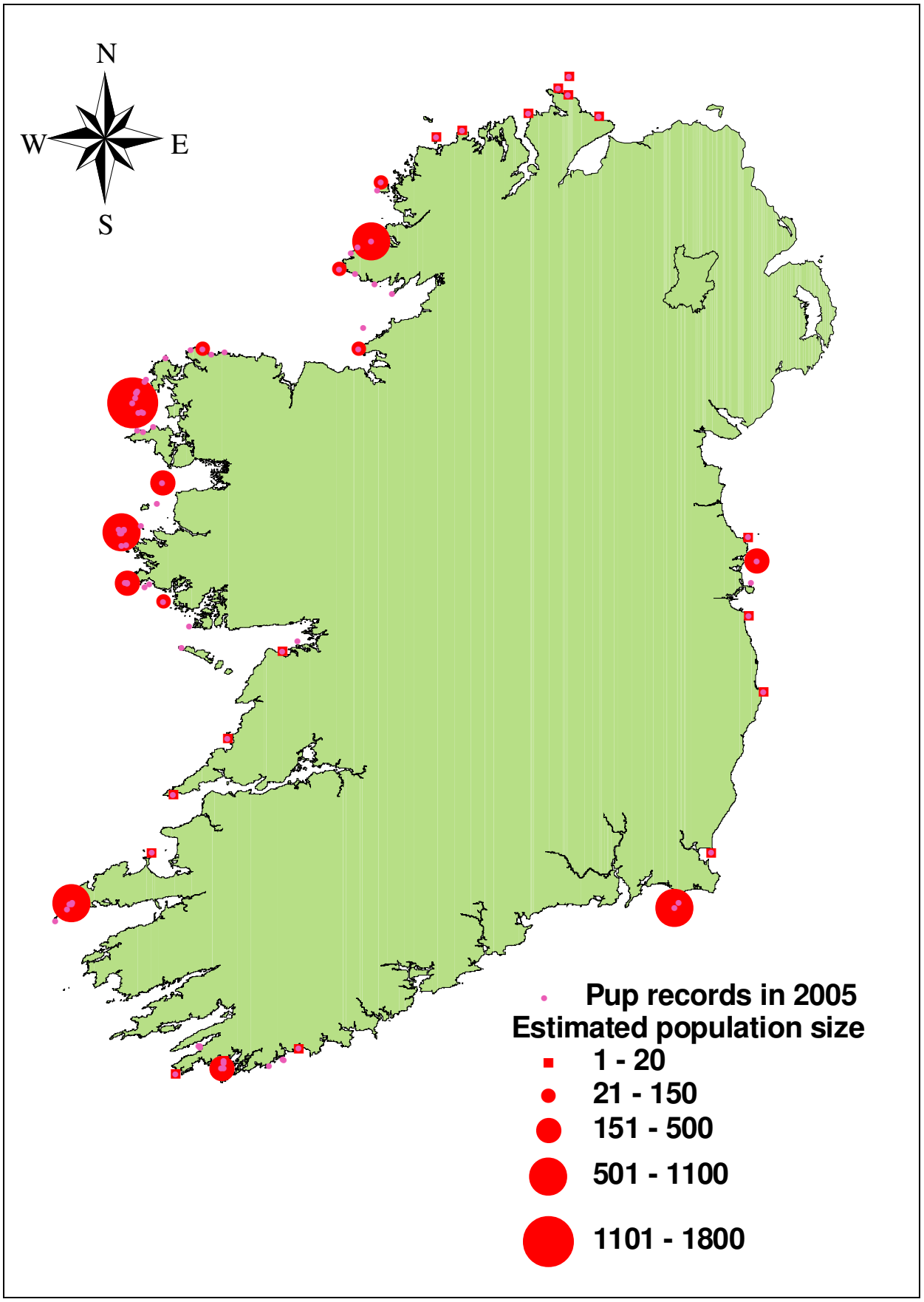


Figure 9. All-age grey seal population sizes and regional distribution derived from data gathered in the Republic of Ireland, August—December 2005. Data for low-production breeding colonies are pooled and included within nearby population estimates as appropriate (*see* Appendix III).

The best available data from the Inishkea Group described a three-fold increase in pup production since 1995 (Fig. 10), corresponding to an hypothetical net annual increase of c. 11.7% in the number of pups born at this breeding colony. The second most studied breeding area in the Republic of Ireland (the Blasket Islands) showed more modest changes overall since broad-scale surveys commenced there in 1996 (Fig. 10). However data for (a) all islands collectively and (b) Beginish recorded a decline in pup production between the 2003 and 2005 seasons (Appendix IV).

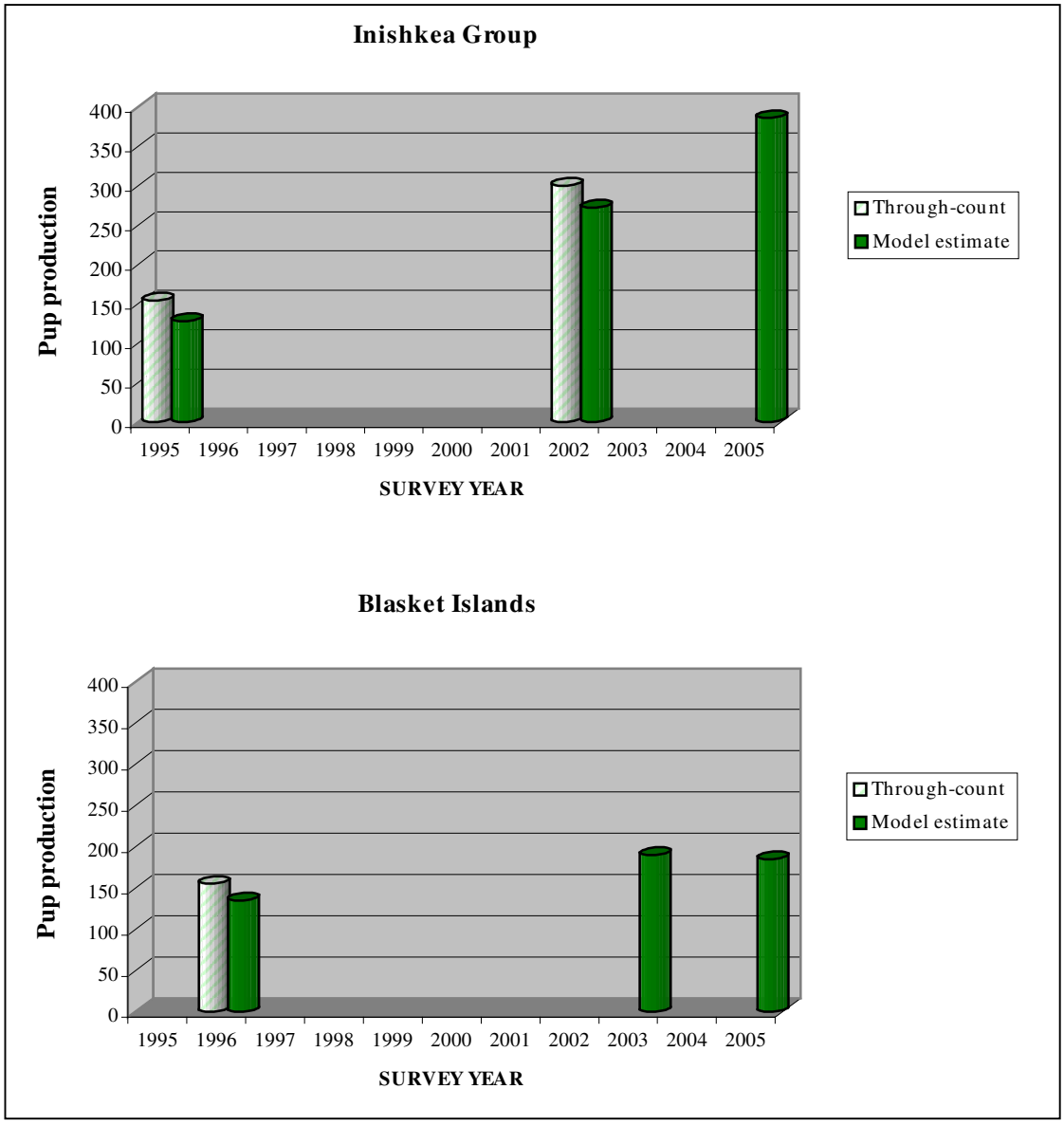


Figure 10. Pup production estimates from two key colonies that have been the main focus of research in the Republic of Ireland since 1994. Unmodelled data are totals from through-count surveys.

Consistent data gathered at the Inishkea Group showed that, while the breeding population as a whole may have grown in the period since 1995, changes in pup production on individual islands have been variable (Fig. 11) with increases in pup numbers on Duvillaun Beg, Inishkea South and Inishkea North, in particular, appearing to drive the overall increase detected over the last decade. In contrast, five breeding

islands stretching from Carrickawilt to Inishglora have shown comparatively little change in pup production since they were first surveyed comprehensively in 1995.

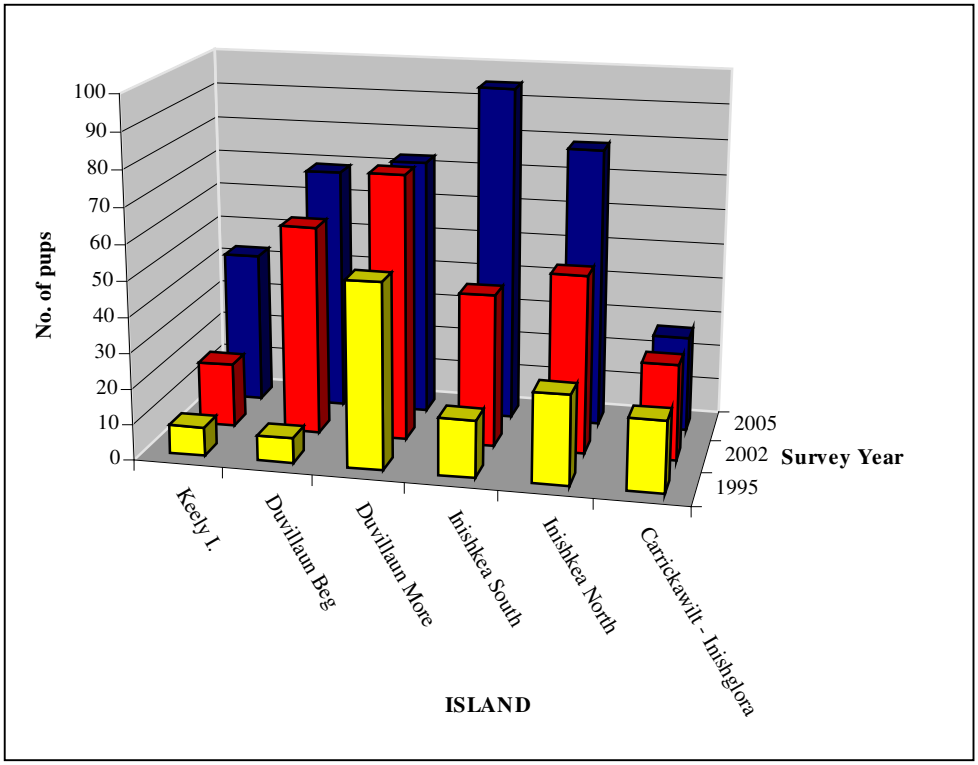


Figure 11. Grey seal pup production data for individual islands within the Inishkea Group since 1995. Data shown are model estimates from ground- and aerial-acquired pup counts.

Pup production recorded on key breeding colonies off the east and southeast coasts (i.e. Lambay I. & Ireland's Eye, Saltee Is.) also described a growth to 2005 figures (Appendix IV). At the Saltee Islands, comparable through-count surveys indicated a potential growth in pup production of 39.1% in the interval between 1998 and 2005 (Fig. 12). This corresponds to a c. 4.8% net annual growth in production to the total 178 pups dye-marked and logged by observers in the present study, with peak numbers ashore recorded more than two weeks earlier in 2005 than in 1998 (Fig. 13). Model-derived estimates of pup production (P_{1998}=86; P_{2005}=163) however suggested a two-fold increase in pup production between survey years, corresponding to a net annual increase of c. 9.6%.

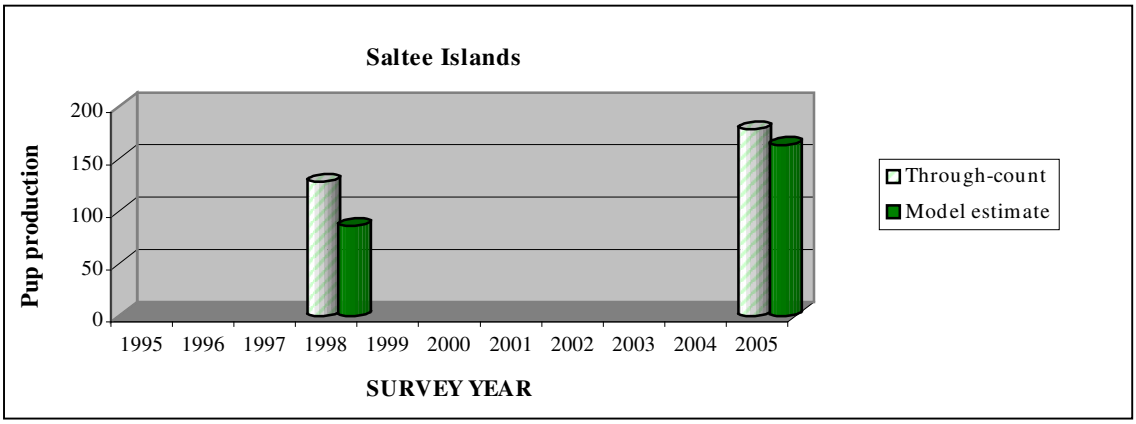


Figure 12. Saltee Islands pup production estimates derived by through-count and model estimation.

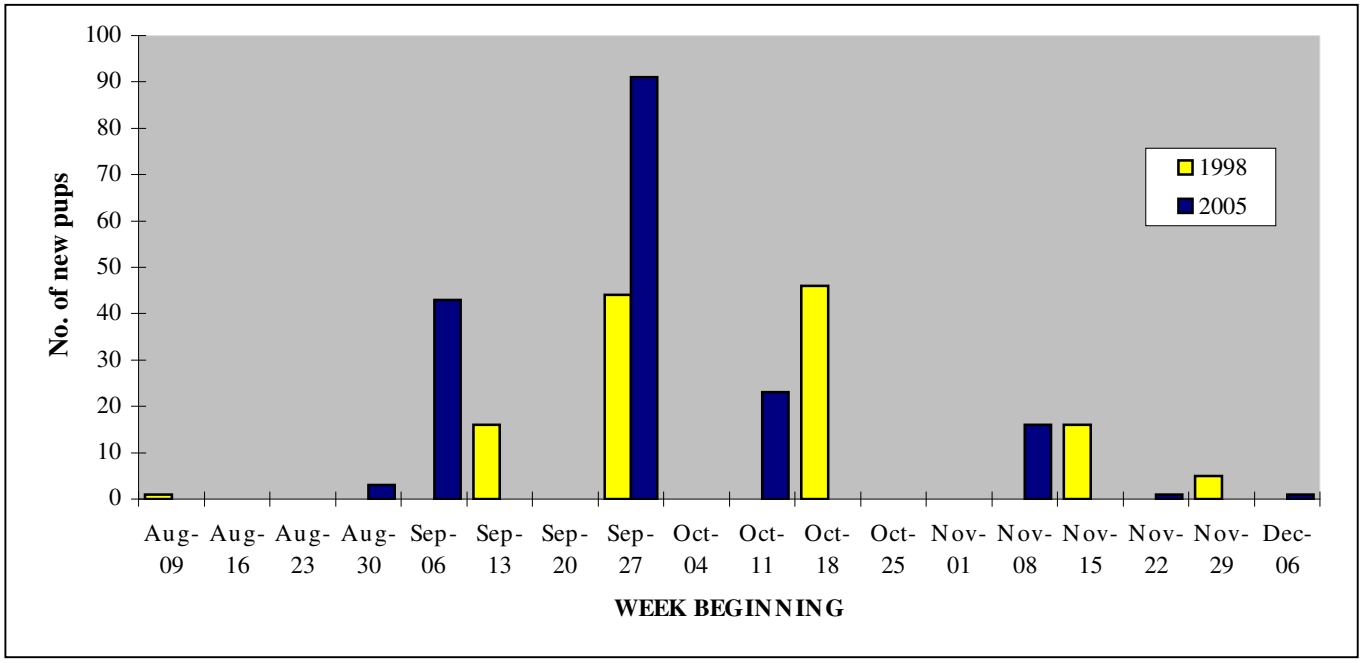


Figure 13. Total counts of newborn grey seal pups recorded at the Saltee Islands during regular through-count surveys in 1998 and 2005.

4. DISCUSSION

Grey seal population estimation

This study formed the first comprehensive assessment of the Republic of Ireland's grey seal population based on first-hand pup production estimates. The primary objectives of the research were achieved satisfactorily and an appropriate foundation now exists for continued population monitoring and management of this protected species in the Republic of Ireland.

The 2005 population estimate of 5,509–7,083 grey seals of all ages represents the highest figure recorded for the Republic of Ireland, exceeding previous breeding-based estimates (2,000-2,500: Summers, 1983; 4,000+: Ó Cadhla & Mackey, 2002) and a summer haul-out estimate of 1,287 grey seals in 2003 (Cronin *et al*., 2004). Care must be taken in interpreting the new Irish figure relative to preceding information, however, since the survey programme carried out in 2005 was more comprehensive in temporal and spatial coverage than any previous survey. Instead the total pup production (1,574 grey seal pups) and corresponding population estimates should be viewed as firm baseline data and minimum estimates against which future assessments will be made. The statistical determination of population trends in Ireland are not yet possible given the absence of a coordinated grey seal monitoring programme. An analysis of data-reliability and time-frames, target colonies and methodology should now be undertaken to determine the best course of future monitoring action.

The relationship between pup counts in a given year and the size of the overall breeding population depend on the population trajectory, its age-structure, adult and juvenile survival, and fecundity rates for adults of different ages (Harwood & Prime, 1978). In the western North Atlantic, exponential population increases as high as 12.8% per year at some breeding colonies (Stobo & Zwanenburg, 1990; Bowen *et al*., 2003) and statistical modelling (Zwanenburg & Bowen, 1990; Hammill *et al*., 1998) suggest that a multiplier of c. 5.0–5.6 may be appropriate in determining all-age population size from pup production data and measurable life history characteristics.

In investigating an appropriate multiplier by which population size in the Republic of Ireland may be inferred from recorded pup production, a number of factors were considered. Firstly, the Republic of Ireland's breeding grey seal population, lying at the southwestern limit of the species' range in the eastern North Atlantic (Bonner, 1972), is considered a component stock of a larger European population stretching from northwestern Russia to France. It is our assumption that individual grey seals inhabiting the Irish coastline undergo similar life histories to their UK-based counterparts, being situated in comparative proximity to one another and capable of long-distance interregional travel, as shown by satellite tracking (McConnell *et al*., 1992; Hammond *et al*., 1993; Vincent *et al*., 2005), photo-identification (Kiely *et al*., 2000) and flipper-tagging studies (A. Hall, SMRU, *unpubl*.; Kiely, 1998; BIM, 2001).

Secondly, the estimated sizes of neighbouring populations in the UK and France have been shown to increase in recent years at average rates of between 3% and 7% (Hiby *et al*., 1996; Duck, 2004; Vincent *et al*, 2005). Evidence gathered in the present study (*see below*) also suggests increases in pup production at key regional colonies. The current population estimate for Britain numbers between 77,100 and 120,800 grey seals of all ages (SMRU,

2004), about 40% of the global population. Over 90% of these animals are associated with breeding sites in Scotland. In contrast very small numbers, no more than a few hundred grey seals, inhabit haul-out and breeding sites in Germany, the Netherlands and France (Abt *et al*., 2002; Reijnders *et al*., 1995; Vincent *et al*., 2005). There are, however, few published life history data available for grey seal stocks within the European region. Since population-level features such as adult and juvenile survival and female fecundity are also not available for grey seals on the island of Ireland, the reliance on a pup:population multiplier of 3.5-4.5, based directly on a sample of 1,036 females and 294 males from the UK (Harwood & Prime, 1978), currently represents the best means available for estimating population size in the Republic of Ireland.

Pup production at key colonies: 1995 to 2005

The investigation of changes in pup production at key Irish breeding colonies suggests that they have not occurred uniformly throughout the region and were not necessarily mirrored in scale by direct estimates from through-count data. Among breeding colonies in Britain increases in pup production as high as 13.3% have been recorded in successive years while trends in the number of pups born may be highly variable between years and from one colony to the next (Duck, 2004). In the absence of an annual monitoring programme in the Republic of Ireland, it is currently difficult to draw watertight conclusions from data gathered across gaps of several years. Nevertheless, the overall post-1995 increases in pup production shown among all but one resurveyed colony (i.e. Slyne Head islands) and indications of significant pup production growth at the Inishkea Group, confirmed as the largest breeding area on the island of Ireland, underline the need for an effective programme of national monitoring by which true population trends may be better evaluated.

The impact of the illegal cull in 2004 at the Blasket Islands, which was the fourth largest breeding colony in the Republic of Ireland in 2005, is difficult to assess at this stage. Yet the small decrease shown in total pup production between 2003 and 2005 is worth noting, particularly since production estimates for the island of Beginish, which in 1996 accounted for 75% of total production (Kiely & Myers, 1998), declined from 155 pups in 2003 (81.6% of the Blasket Is. total) to 134 pups in 2005 (72.4%). The 1996 pup production estimate for Beginish was 107 (Appendix IV). Since the majority of grey seals killed in 2004 were newborn pups (P. Foley, NPWS, *unpubl*.), significant changes in pup production among all islands may not occur until at least 2008 when reduced recruitment to the breeding population from the 2003 pup cohort first becomes a possibility.

Considering that much of the culling activity took place on Beginish, it is possible that a shift in the distribution of pupping occurred among these islands into the 2005 season. This might explain the relatively low decline in overall pup production from estimates of 190 in 2003 to 185 in 2005. Data gathered at the Inishkea Group in the years surrounding illegal culling activity (1979-82) and thereafter described a shift in the distribution of pupping among key islands in the archipelago (Kiely & Myers, 1998). Data delivered by the present study again show that two once-important breeding islands on which culling activity and associated disturbances occurred between 1979 and 1983, have not recovered in pup production terms and do not mirror the upward production changes shown since 1995 on neighbouring islands.

It is unclear why some model estimates of grey seal pup production differed markedly from the equivalent through-count figures or why the degree of difference between the two tended to be higher for data recorded between 1995 and 1998 than for more recent pup counts. Coefficients of variation delivered by the modelling process tended to be higher from the earlier pup count data, yet were very satisfactory from most sites surveyed in 2002, 2003 and 2005. It may be that smaller individual counts and site-specific variability in the pattern of births at Irish sites are partly responsible. Through-count estimates from the Republic of Ireland have also tended to cover a wider span of the breeding season (i.e. August to December; Fig. 13) than did the samples used in the modelling process (i.e. mid-September to mid-November). In this manner, perhaps the broader time-scale over which pupping can occur at Irish breeding colonies deliver significant data outliers to the birth-curve predicted by the *PEST* model.

It may also be that a number of standard model parameters used (e.g. time to moult, time to leaving), which are based on extensive pup data from the UK, do not fit exactly the observed equivalents at individual Irish colonies. However, considering that the *PEST* model is based on a pup production dataset several orders of magnitude greater than any currently available for Ireland and that, by and large, model fits and CVs from 2005 pup count data were very satisfactory, continued use of the *PEST* model is recommended for accuracy and comparative purposes into the future. Further research in the Republic of Ireland should take account of these findings and seek to improve the understanding of the grey seal breeding process across a range of key sites and habitat types.

Grey seal breeding distribution – Past and present

All of the seven key breeding colonies recorded in 2005 (Table V) have been flagged by previous research as important breeding areas (Lockley, 1966; Warner, 1979; Summers 1980, 1983; *see also* Table I). However, the 2005 survey allowed their numerical significance to be evaluated, revised and set within the framework of new data from around the entire national coastline. In this context the islands of northwest Galway and the mainland of southwest Donegal, in particular, delivered comprehensive new data of national and regional importance.

While differences in the distribution of breeding grey seals were observed in 2005 relative to what was known previously, it should be remembered that a significant amount of time has passed since early surveys by R.M. Lockley (1966) and the Forestry & Wildlife Service (Warner, 1979; Summers, 1980, 1983) and such historic information is not strictly comparable with the new dataset. For example, sites historically noted to contain grey seal pups ashore may not all have been sites at which the pups were in fact born. In 2005 a number of such sites, which contained individual moulted pups on a single survey that had not been present before or after that visit, were identified (e.g. Mucklaghbeg, Co. Kerry). Clearly caution is required in attempting to interpret breeding distribution based on very low pup numbers (i.e. total counts in single figures). This and the earlier than expected timing of breeding observed in Donegal may explain why eight Category A locations, at which small numbers of pups were recorded in November 2003 (Cronin *et al*., 2007b), did not show evidence of breeding in 2005.

Inconsistencies in positional information given for earlier records may also have played a role in the discrepancies between the exact locations of pups recorded in 2005 and historically. The northwest coast of Mayo and southwest coast of Donegal, in particular,

in their complexity present formidable challenges in the accurate determination of breeding site coordinates. An appropriate future approach may be to link geo-referenced positional data to pupping data whether recorded from the ground or air.

It is also noteworthy that Co. Donegal delivered comparatively few breeding sites to the north of Aran Island in 2005, in spite of extensive habitat potential and the presence of known haul-out sites on Tory Island, Inishtrahull and several smaller islands (Cronin *et al*., 2004; Cronin *et al*., 2007b; O. Ó Cadhla, CMRC, *unpubl*.). Aerial photography at Inishtrahull, in particular, recorded haul-out sizes of several hundred adult and juvenile grey seals (O. Ó Cadhla, CMRC, *unpubl*.), yet recorded pup production on the island totalled just four pups in 2005 and five in 2003 (Cronin *et al*., 2007b). It is currently unclear why this island, which appears to contain a broad area of suitable habitat and is a haul-out location for nationally significant numbers of grey seals year-round (D. Duggan & E. Johnston, NPWS, *unpubl*.), does not appear to constitute a breeding colony of importance according to data gathered in 2003 and 2005, 2006 and 2007 (E. Johnston, NPWS & O. Ó Cadhla, CMRC, *unpubl.)*. There is no other example of such a location in the Republic of Ireland.

Production, mortality and pup detectability

The present study ultimately delivered a dataset describing the minimum production of grey seal pups born during the 2005 season in the Republic of Ireland. Photographic records of pups in caves or swimming in shallow waters, and the possibility of pups being born and subsequently lost in the interval between surveys, highlight the probability that some newborn pups were missed in 2005, while every effort was made to minimise this number.

A significant feature of both ground- and aerial-acquired count data from 2005 was the relatively low level of pup mortality observed at breeding sites. Regional proportions of dead pups among the 3,062 aerial-acquired pup records were lower than 2%. Within the small sample size available, ground-truthing data did not appear to indicate a significant difference between pup mortality recorded from the ground and from the air. Ground count data delivered from Lambay Island and Ireland's Eye, the Saltee Islands and the Blasket Islands, all of which were surveyed relatively consistently through the breeding season, also showed on-site mortality levels of less than four dead pups per site over the 2005 season.

Recent through-count surveys in the Republic of Ireland have described relatively low numbers of dead pups ashore from as low as 2.0% (Lambay Island & Ireland's Eye 1998 – Lidgard *et al*., 2001) and 2.6% (Blasket Islands 1996 – Kiely & Myers, 1998) of recorded pup production to maxima of 8.6% (Saltee Islands 1998 – Lidgard *et al*., 2001) and 11.7% (Slyne Head & Hen Island – Ó Cadhla *et al*., 2005). While these figures may represent realistic estimates of true on-site mortality, research at comparable breeding sites in the UK indicate that the detected level of pup mortality may be strongly linked to the shore environment on which it occurs (Anderson *et al*., 1979). Thus beach areas with space above high water mark allow dead pups to remain ashore, whereas cliff-backed sites with limited beach space at high tide see the greater removal of dead pups.

The extent to which (a) pups can be lost from breeding sites between survey intervals, and (b) to which the detectability of living and dead pups may be affected by high tides, wave

action and animal density among various habitat types are unknown in an Irish context. Although the ground-truthing exercises in 2005 allowed a useful comparison of independent ground- and aerial-acquired pup records, it is possible that some dead pups were not specifically identified as such in the wider image analysis process since individual dead pups can resemble living pups depending on their posture, colouration, position on the shore and state of decomposition (e.g. Plate 12). While the statistical estimation process allows for pup losses or missed detections to a 5% level, these are based on data from the Isle of May in the UK and a detailed field investigation of pup mortality at one or more key Irish breeding sites would be more appropriate.

The occurrence of cave-breeding by grey seals in the Republic of Ireland was noted both from historic information, new aerial survey data from along the western seaboard and ground survey results from the coasts of Co. Cork and Co. Dublin. Although the data review identified a number of Category A breeding sites along the Waterford coast no pups were observed on ground surveys carried out in 2005, suggesting that cave sites may be the preferred breeding habitat in such areas or perhaps that annual pupping in the region is less predictable than at larger, more established breeding colonies. While grey seal pups are known to be born in caves on Lambay Island, Ireland's Eye and the Great Saltee Island (Kiely *et al*., 2000), research at the Great Saltee Island (Lidgard *et al*., 2001; present study, *unpubl*.) indicates that the use of such sites may decline in the latter half of the breeding season.

A thorough analysis of pup distribution across the full range of habitats containing pups in 2005 was not performed at this stage. Its investigation would certainly be worthwhile, and should remain an important component of continued national monitoring effort so that the habitat requirements of breeding grey seals in the Republic of Ireland might be better understood. A dedicated effort to survey identified cave-breeding sites around the Irish coast should also be considered to determine the proportion of overall pup production that goes undetected when conducting broad-scale aerial surveys.

Aerial survey operations in 2005

The extensive aerial survey programme performed in 2005 was, on the whole, effective in producing the intended operational results. While its completion was due to a range of factors including background research, planning and the invaluable input of a wide range of contributors, the prevailing weather conditions between August and December, though challenging for both aerial and boat-based survey effort, allowed sufficient windows of opportunity for all research tasks to be performed.

Aerial survey operations were greatly assisted by the choice and availability of aircraft to meet the research and safety requirements of the project team. Conducting aerial surveys along Ireland's coastline and exposed Atlantic seaboard, in particular, is not without risk particularly in complex indented areas with high coastal cliffs of 600 feet or more in altitude. The use of an helicopter in such areas made for safer flying and facilitated the necessary, more painstaking approach to aerial photography. In contrast, the use of a lighter single-engine aircraft such as the *Cessna 172* can be difficult in such circumstances and carries a greater risk in all but near-optimal flying conditions. Thus the number of days on which such an aircraft may be used are fewer and surveys are more prone to local air turbulence, as experienced in a number of earlier studies (D. Strong & G. O'Donnell, NPWS, *unpubl*.; Ó Cadhla *et al*., 2006; Cronin *et al*., 2007b). Nevertheless, between the three

aircraft types used in 2005 just three of 148 survey locations received one fewer survey visit than their intended target. Thus future use of all such aircraft should be considered as appropriate to the survey area, research objectives and safety requirements.

In a small number of cases, local wind conditions and turbulence during aerial surveys were consistently difficult, restricting access to sites at the optimal altitude and distance from the coastline and requiring repeated aerial passes of sites to provide the necessary data and imagery. The main locations at which such conditions persisted were Horn Head and along the north coast of the Inishowen peninsula in Co. Donegal, and at Sauce Creek which lies at the northern base of Mount Brandon, Co. Kerry. All had indicated very low numbers or no pups from aerial imagery and on-board observation. To validate such findings on the ground in one case, the entire north coast of the Inishowen peninsula was covered by boat in October 2005. Future ground-level surveys of Horn Head, Sauce Creek and other sites that prove consistently difficult to survey by air would also be appropriate for confirmatory purposes. As in 2005, this would allow for optimal use of air-time by reducing the need for repeated aerial passes at such sites.

The large image bank accumulated in 2005 using digital still photography and videography, while time-consuming to analyse, increased the probability of detecting pups and confidence in the accuracy of pup production estimates. Individual grey seal pups that had not been seen with the naked eye or binoculars when flying were frequently recorded from the still imagery, while extensive photography of Category B sites which gave indications that pups may be present (e.g. due to the presence of adults) often yielded positive results. In this manner a total of 30 new locations were verified as grey seal breeding locations in 2005.

Ground surveys and truthing of aerial survey data

Results from the ground survey programme were also encouraging both in operability and data terms. Gaining access to and surveying offshore islands by boat can be difficult in the months of September to December, particularly along the Atlantic seaboard and the selection of islands for boat-based and ground-based survey activity in 2005 appeared to have been appropriate, allowing the full complement of intended surveys to be performed.

Poor sea conditions can occasionally hamper research activity, however, and previous ground-level surveys in western Ireland (e.g. Kiely & Myers, 1998; Ó Cadhla & Strong, 2003; Ó Cadhla *et al*., 2005) commonly suffered at least one delay in the target 10-15 day survey schedule due to bad weather. In 2005 a persistent heavy swell along the south coast, to which the Saltee Islands are exposed, meant that an unusually wide interval of 32 days between visits by survey personnel was incurred there in late October and early November. Aerial survey methods might alleviate the difficulty in such circumstances although records of pups from some cave sites might have to be forfeited, as would be the case on the southern flank of Great Saltee Island.

Ground-truthing exercises carried out in 2005 indicated that the use of digital aerial imagery for pup counting was an effective means of assessing pup production and minimum population size on a national scale, confirming earlier methodological evaluations (D. Strong & G. O'Donnell, NPWS, *unpubl*.; Ó Cadhla *et al*., 2006; Cronin *et al*., 2007b). Although it was difficult to synchronise aerial and ground survey effort exactly,

differences between aerial- and ground-acquired counts largely fell within acceptable limits and the respective datasets were not significantly different. Examination of larger discrepancies between individual aerial- and ground-count pairs certainly appeared to be linked to either local topographical/habitat effects in the form of particular enclosed gullies, or to differences between the intended and actual sections of habitat investigated on the ground.

The value and importance of effective ground-truthing in the context of new Irish research was also shown in the 2003 harbour seal population assessment (Cronin *et al*., 2004). In addition to the crucial data validation provided by this exercise in 2005, the grey seal field assessment allowed all participating groups to become familiar with sites and methodology on a national scale, features which had not been present heretofore. Ground-truthing experiments during future population assessments will allow for further refinement of the survey method while continuing to deliver valuable ground-level data to complement each national survey.

As with any broad-scale survey of this nature, there is always room for improvement and it is intended that the lessons learned from research in 2005-2006 will inform future surveys and assist in optimising continued research effort.

5. CONCLUSIONS

5.1 Implementation of the research project

The population assessment project was implemented satisfactorily and valuable expertise was gained by the project team in the logistics, methods and analysis necessary for future such research in the Republic of Ireland.

5.2 Grey seal breeding population size in the Republic of Ireland

The current grey seal population estimate for the Republic of Ireland is 5,509—7,083 seals of all ages. This is a minimum estimate and as such represents the appropriate national baseline figure.

5.3 Areas of importance for breeding grey seals, regional and local

The 2005 population assessment underlined the importance on a national scale of seven key breeding colonies located in Counties Donegal (southwest), Mayo (Inishkea Group), Galway (Inishshark, Inishgort & adjacent islands; Slyne Head islands), Kerry (Blasket Islands), Wexford (Saltee Islands) and Dublin (Lambay Island & Ireland's Eye). Other breeding sites of regional and local importance were identified in 2005. Most occurred along the Atlantic coastline from west Cork to Donegal.

5.4 The timing of breeding along the Irish coastline in 2005

Pup production analysis highlighted considerable variation in estimates of mean grey seal birth date for the Republic of Ireland, from the third week of September to mid-October. A normal distribution model plot describing births over the season was appropriate for most Irish breeding colonies.

5.5 Population changes at key breeding colonies

Changes in grey seal pup production, and consequently in estimated population size, were recorded at most breeding colonies studied consistently since 1994, although the data fall short of indicating clear population trends at this time. The observed degree of increase in pup production was variable between sites and highest at the Inishkea Group, Ireland's largest breeding colony. A small decrease in annual pup production was noted at the Blasket Islands following an illegal cull, which occurred there in 2004.

6. RECOMMENDATIONS

6.1 Future population assessments on the island of Ireland

It is recommended that the methods described in the present study are used as the basis for future population assessments in the Republic of Ireland. If possible, future surveys seeking to estimate population size should be coordinated with similar research effort in Northern Ireland, in order to deliver comprehensive figures for the island of Ireland.

6.2 National monitoring programme for grey seals

It is recommended that the momentum generated by this research should now be directed towards an annual monitoring programme at key grey seal breeding colonies in the Republic of Ireland. This could be implemented relatively easily, operated in a relatively low-cost manner and the data reviewed annually in order to determine appropriate timeframes for ongoing large-scale population assessments of the kind performed in 2005.

6.3 Priority research areas

It is recommended that a number of priority areas for population research should be supported, based on the information gathered in 2005 and significant information gaps that remain. These are:

1) Seasonal assessment of population size and distribution (e.g. moult & summer seasons);

2) Studies of grey seal movements and foraging ecology from regional population centres;

3) Dedicated research into grey seal habitat preferences, pup mortality and population biology at key accessible breeding colonies (e.g. Inishkea Group, Blasket Islands, Saltee Islands);

4) Ground-level investigations of cave breeding by grey seals in the Republic of Ireland.

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Go raibh míle maith agaibh go léir.

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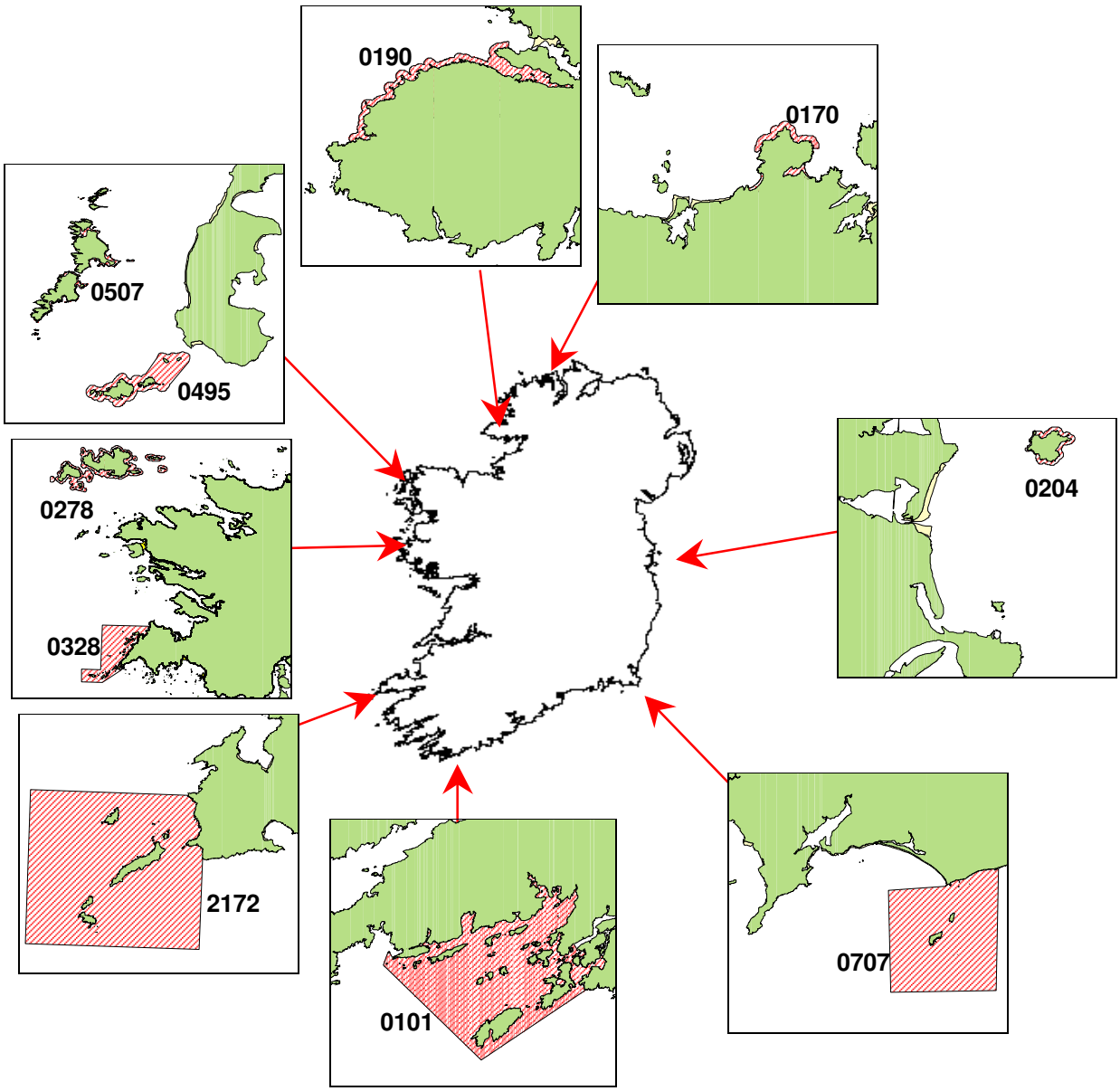
APPENDIX I DESIGNATED SPECIAL AREAS OF CONSERVATION (SACs) FOR GREY SEALS IN THE REPUBLIC OF IRELAND.



Legend:

Site Code	*Name of site*	*County*
000204	LAMBAY ISLAND	DUBLIN
000707	SALTEE ISLANDS	WEXFORD
000101	ROARINGWATER BAY AND ISLANDS	CORK
002172	BLASKET ISLANDS	KERRY
000328	SLYNE HEAD ISLANDS	GALWAY
000278	INISHBOFIN AND INISHSHARK	GALWAY
000495	DUVILLAUN ISLANDS	MAYO
000507	INISHKEA ISLANDS	MAYO
000190	SLIEVE TOOEY/ TORMORE ISLAND/ LOUGHROS BEG BAY	DONEGAL
000147	HORN HEAD AND RINCLEVAN	DONEGAL

APPENDIX II PROJECT TEAM FOR THE 2005 POPULATION ASSESSMENT.

Project Management: Oliver Ó Cadhla, Denis Strong, Ciaran O'Keeffe

Data review/Reconnaissance: Oliver Ó Cadhla, Denis Strong, David Lyons, Ciaran O'Keeffe with the assistance of the Irish Air Corps

Survey design: Oliver Ó Cadhla, Denis Strong, Callan Duck, Michelle Cronin

Breeding season aerial survey teams:

Aer Arann Islands pilots Des Collins, Alan Grimes, Simon Myatt

Search Area A (northwest)	*Search Area B (west)*	*Search Area C (southwest)*	*Search Area D (east)*
Oliver Ó Cadhla	Oliver Ó Cadhla	Michelle Cronin	Oliver Ó Cadhla
Cameron Clotworthy	Cameron Clotworthy	Pascal Dower	Irish Air Corps – 104 Sqn
Dave Duggan	Rob Holloway	Paddy Graham	
Emmet Johnston	Aonghus Ó Dónaill	Clare Heardman	
Irene O'Brien	Barry O'Donoghue	David Lyons	
Tim Roderick	Denis Strong	Declan O'Donnell	
Pat Vaughan		Danny O'Keeffe	

Ground survey teams:

Dublin	*Wexford*	*East Cork & Waterford*	*West Cork & Kerry*	*Galway & Mayo*	*Donegal*
Ciaran O'Keeffe	Tony Murray	Pat Smiddy	Pascal Dower	Denis Strong	Emer Magee
Richard Nairn	Wesley Atkinson	Brian Duffy	Declan O'Donnell	Ger O'Donnell	Carl Byrne
Paul Murphy	Pádraig Comerford	Cyril Saich	Frank McMahon	Helen Carty	Robbie Millar
Kieran Buckley	Damien Clarke		Pat Foley	Marie Duffy	Larry McDaid
Ferdia Marnell	Jimi Conroy		Paddy Graham	Rob Holloway	Séamus McGinty
Oscar Merne	Paul Duffy		Clare Heardman	Eoin McGreal	
	Leonard Floyd		David Lyons	Oliver Ó Cadhla	
	Ben McCabe		Don McMahon		
			Éamon Meskell		
			Danny O'Keeffe		
			Tim O'Donoghue		
			Michael O'Sullivan		

NPWS coordinators: Dave Duggan (NW), Denis Strong (W), Ger O'Donnell (W), Frank McMahon (SW), Declan O'Donnell (SW), Cyril Saich (SE), Wesley Atkinson (E)

Irish Air Corps assistance:

Coordination & Operations	104 Squadron – *Cessna 172*	303 Squadron – *Alouette III*	101 Squadron – *CASA*
Comdt Owen McGrath (104 Squadron)	Lt Emmet Farrelly	Capt Colin Duffy	Capt Gerry Fitzpatrick
Comdt Martin Clancy (303 Squadron)	Lt Barry Kelly	Flt Sgt Niall Guilfoyle	Lt Kenneth Byrne
Comdt Ronan Verling (101 Squadron)	Lt Jonathan Lynch	Capt Séamus McNamara	Sgt Joe Moore
Capt Mark Prendergast (104 Squadron)	Lt Finbarr McArdle	Sgt Red O'Keane	Cpl Damien Faulkner
Capt Matt Quinlan (104 Squadron)	Lt Seán McCarthy	Capt James O'Reilly	
Capt James Brady (303 Squadron)	Lt Oisín McGrath	Cpl Frank Coughlan	
Cpl Elaine Fitzgerald (Helicopter Operations)	Lt Dave O'Mara	Capt Lee Brennan	
		Cpl Donal Behan	
		Capt Jake McCarthy	
		Armn Kieran Tobin	
		Capt David Browne	
		Cpl David Hennessey	

Image analysis Mary Coleman, Oliver Ó Cadhla

Data analysis: Oliver Ó Cadhla, Callan Duck, Mary Coleman, Lex Hiby

APPENDIX III PUP PRODUCTION DATA FOR THE REPUBLIC OF IRELAND, 2005.

Locations and sites covered during the 2005 grey seal population assessment, selected data and estimated individual (P_i) and grouped (P_g) pup productions delivered by the survey programme.

[I. = Island; Hd. = Head; n/d = not determinable; * = data incorporated in grouped total].

Location Number	Category	County	Site/Area name	Lat. °N	Long. °W	No. of surveys	Maximum pup count	Mean birth date	P_i	P_g
1	C	**Cork**	Capel I.	51.883	7.853	1	0			
2	C	Cork	Ballycotton Islands	51.826	7.986	1	0			
3	C	Cork	Lahard	51.786	8.166	2	0			
4	C	Cork	Doonavanig	51.751	8.302	1	0			
5	C	Cork	Holeopen Bay	51.620	8.540	1	0			
6	C	Cork	Rochestown	51.640	8.610	1	0			
7	C	Cork	Coolim cliffs	51.604	8.692	1	0			
	C	Cork	Seven Heads	51.573	8.740	1	0			
8	C	Cork	Brownstown	51.574	8.879	1	0			
	C	Cork	Dunowen	51.540	8.920	1	0			
9	C	Cork	Castle Bay	51.560	9.030	1	1	n/d	**1**	
10	A	Cork	High I.	51.514	9.125	6	1	13 Oct		*
	A	Cork	Low I.	51.516	9.129	6	2	13 Oct		*
	C	Cork	Rabbit I.	51.530	9.122	1	0			
11	C	Cork	Horse I.	51.507	9.184	1	0			
12	B	Cork	Farranconnor	51.492	9.214	6	2	13 Oct		*
13	C	Cork	Gokane	51.488	9.261	1	0			
14	B	Cork	Kedge I.	51.463	9.343	6	0			
15	C	Cork	Illaunbrock	51.453	9.442	1	0			
16	A	Cork	Clear I. – Cape Clear	51.427	9.520	6	0			
17	A	Cork	Calf I. West	51.474	9.518	6	16	13 Oct		*
	A	Cork	Calf I. Middle	51.479	9.504	6	7	13 Oct		*
	A	Cork	Calf I. East	51.483	9.488	6	0			
	A	Cork	Carthy's Islands	51.495	9.506	6	2	13 Oct		*
18	C	Cork	Castle I.	51.507	9.506	1	1	n/d	**1**	
	C	Cork	Skeam West	51.503	9.459	1	0			
	C	Cork	Skeam East	51.505	9.444	1	0			
19	B	Cork	Goat Islands	51.487	9.603	6	0			
	B	Cork	Illaunricmonia	51.484	9.616	6	0			
	C	Cork	Dick's I.	51.496	9.637	1	0			
20	C	Cork	Mizen Hd.	51.451	9.810	1	1	n/d	**1**	
	C	Cork	Dunlough – south	51.477	9.822	1	0			
21	B	Cork	Knocknamaddree	51.513	9.770	6	0			
22	A	Cork	Carbery I.	51.562	9.669	6	3	13 Oct		*
	A	Cork	Furze I.	51.559	9.657	6	7	13 Oct		*
	A	Cork	Cold I.	51.565	9.657	6	2	13 Oct		**47**
	A	Cork	Horse I.	51.558	9.650	6	0			
23	B	Cork	Ballyieragh	51.550	9.790	6	0			
24	C	Cork	Sheep's Hd. to Foilakilly	51.583	9.770	1	0			
25	C	Cork	Bear I. – south	51.615	9.879	1	0			
	C	Cork	Dunboy – south	51.620	9.931	1	0			
26	C	Cork	Loughane More	51.600	10.090	1	0			
27	C	Cork	Foher	51.623	10.090	1	0			
28	C	Cork	Inishfarnard	51.711	10.020	1	0			
29	C	**Kerry**	Sherky I. to Inishkeragh	51.790	9.900	1	0			
	C	Kerry	Illaunleagh	51.796	9.942	1	0			
30	B	Kerry	Two Headed I.	51.737	10.152	6	0			
	B	Kerry	Moylaun I.	51.739	10.171	6	0			
31	C	Kerry	Deenish I.	51.735	10.220	1	0			

Location Number	Category	County	Site/Area name	Lat. °N	Long. °W	No. of surveys	Maximum pup count	Mean birth date	P_i	P_g
32	B	Kerry	Pointacannigavallig	51.773	10.193	6	0			
33	C	Kerry	Ducalla Hd. – east	51.801	10.342	1	0			
34	C	Kerry	Foilnageragh	51.870	10.389	1	0			
35	B	Kerry	Valencia I. – Coosnaraka	51.908	10.409	6	0			
35	B	Kerry	Valencia I. – Crush north	51.914	10.380	6	0			
36	C	Kerry	Lamb I.	51.942	10.299	1	0			
	C	Kerry	Killelan – north	51.963	10.300	1	0			
37	B	Kerry	Canglass to Carrigower	51.992	10.243	6	0			
38	C	Kerry	Cooscreagh	52.017	10.157	1	0			
	C	Kerry	Coostemple	52.022	10.146	1	0			
39	C	Kerry	Gleensk - north	52.040	10.060	1	0			
40	C	Kerry	Acres	52.128	10.082	1	0			
	C	Kerry	Glan Mountain	52.116	10.108	1	0			
41	A	Kerry	Inishvickillane	52.044	10.608	6	10	7 Oct		*
42	A	Kerry	Great Blasket I.	52.093	10.537	7	20	7 Oct		*
	A	Kerry	Beginish	52.115	10.507	7	76	7 Oct	134	*
	A	Kerry	Young's I.	52.120	10.505	7	4	7 Oct		*
	A	Kerry	Illaunbwee	52.112	10.523	7	4	7 Oct		**185**
43	C	Kerry	Clogher Hd. – southeast	52.145	10.470	1	0			
44	B	Kerry	Sauce Creek	52.272	10.212	4	0			
45	B	Kerry	Illaunimmil	52.333	10.049	7	0			
	B	Kerry	Illauntannig to Illaunboe	52.328	10.022	7	0			
	B	Kerry	Mucklaghbeg	52.327	10.000	7	1	n/d	**1**	
	B	Kerry	Illaunturlogh	52.326	10.013	7	0			
46	C	Kerry	Kerry Hd. to Kilmore	52.437	9.819	1	0			
47	C	Kerry	Doon to Kilconly	52.538	9.669	1	0			
48	C	**Clare**	Loop Hd. to Rehy Hill	52.561	9.870	3	1	n/d	**1**	
49	C	Clare	Ross to Moveen	52.634	9.773	1	0			
	C	Clare	Corbally – west	52.702	9.652	1	0			
	C	Clare	Bealnalicka	52.726	9.623	1	0			
50	B	Clare	Mattle I.	52.790	9.525	5	1	n/d	**1**	
51	A	Clare	Mutton I.	52.811	9.526	5	0			
	B	Clare	Carrickaneelwar	52.824	9.509	5	0			
52	C	Clare	Freagh to Rinneen	52.890	9.420	1	0			
53	B	Clare	Ballylaan – west	52.943	9.474	5	0			
	B	Clare	Cliffs of Moher	52.969	9.430	5	0			
54	C	**Galway**	Straw I.	53.117	9.629	1	0			
55	B	Galway	Brannock I.	53.146	9.839	6	1	30 Sept		*
	B	Galway	Rock I.	53.148	9.858	6	0			
56	A	Galway	Deer I.	53.184	9.073	6	6	30 Sept		*
57	C	Clare	Farthing Rocks	53.141	9.175	1	1	n/d	**1**	
58	C	Galway	Illaunnanownim	53.223	9.693	1	0			
59	B	Galway	Eagle Rock	53.234	9.796	6	2	30 Sept		*
60	B	Galway	Birmore I.	53.273	9.794	6	0			
	B	Galway	Inishmuskerry	53.274	9.826	6	0			
	B	Galway	Duck I.	53.280	9.847	6	0			
61	C	Galway	Illauneeragh	53.280	9.738	1	0			
	C	Galway	Illaunmaan	53.286	9.758	1	0			
62	B	Galway	Avery I.	53.304	9.894	6	0			
	B	Galway	Wheroon I.	53.306	9.904	6	0			
	B	Galway	St. Macdara's I.	53.305	9.920	6	0			
63	C	Galway	Skerd Rocks	53.257	10.008	1	0			
64	B	Galway	Croaghnakeela I.	53.326	9.972	6	7	30 Sept		*
	B	Galway	Illauncroagh Beg	53.340	9.958	6	0			
	B	Galway	Illauncroagh More	53.346	9.963	6	0			

Location Number	Category	County	Site/Area name	Lat. °N	Long. °W	No. of surveys	Maximum pup count	Mean birth date	P_i	P_g
65	A	Galway	Wherune I.	53.395	10.068	6	3	30 Sept		*
66	A	Galway	Hen I.	53.382	10.094	6	11	30 Sept		**29**
	C	Galway	Carrickacammer	53.391	10.122	1	0			
67	C	Galway	Carrickfia	53.407	10.158	1	0			
68	A	Galway	Ferroon Rocks	53.396	10.215	6	32	16 Oct	45	*
	A	Galway	Illaunamid	53.398	10.230	6	14	16 Oct		*
	A	Galway	Chapel I.	53.398	10.213	6	1	16 Oct		**68**
69	B	Galway	Carrickrana Rocks	53.487	10.159	6	0			
69	B	Galway	Eeshal I.	53.507	10.171	6	0			
	B	Galway	Cruagh	53.524	10.217	6	0			
70	A	Galway	High I.	53.546	10.258	6	6	7 Oct		*
	A	Galway	Friar I.	53.549	10.230	6	7	7 Oct		*
71	A	Galway	Glassillan	53.595	10.271	6	15	7 Oct		*
	A	Galway	Inishgort	53.597	10.263	6	36	7 Oct	75	**104**
	B	Galway	Black Rock	53.594	10.276	6	0			
71	A	Galway	Inishshark	53.610	10.280	6	79	5 Oct		*
	A	Galway	Inishskinnymore	53.605	10.248	6	1	5 Oct		*
	A	Galway	Inishskinnybeg	53.609	10.249	6	2	5 Oct		*
72	C	Galway	Inishlyon	53.612	10.169	1	0			
73	B	Galway	Davillaun	53.627	10.135	6	2	5 Oct		**131**
74	C	Galway	Inisbroon	53.608	10.066	1	0			
	C	Galway	Freaghillaun North	53.616	10.016	1	0			
	C	Galway	Crump I.	53.622	9.999	1	0			
75	C	**Mayo**	Frehill I.	53.662	9.956	1	0			
	C	Mayo	Govern I.	53.655	9.940	1	0			
76	B	Mayo	Inishdalla	53.681	10.072	6	0			
77	C	Mayo	Inishturk – northeast	53.712	10.097	1	0			
78	B	Mayo	Caher I.	53.717	10.030	6	1	30 Sept		*
79	A	Mayo	Clare I.	53.800	10.000	6	15	30 Sept		*
80	C	Mayo	Clew Bay - south	53.809	9.659	1	0			
81	C	Mayo	Clew Bay - centre	53.853	9.655	1	0			
	C	Mayo	Clew Bay - north	53.880	9.708	1	0			
82	B	Mayo	Achill I. – Dooega west	53.929	10.056	6	0			
83	C	Mayo	Carrickmore South	53.960	10.163	1	0			
84	A	Mayo	Achill I. - Saddle Hd.	54.006	10.182	6	16	30 Sept		*
85	B	Mayo	Achill I. – Annagh Strand	54.001	10.139	6	4	30 Sept		*
86	B	Mayo	Achill I. – Doogort West	54.022	10.072	6	1	30 Sept		**59**
87	A	Mayo	Keely I.	54.078	10.140	6	30	7 Oct	**43**	
87	A	Mayo	Duvillaun Beg	54.078	10.152	6	58	30 Sept	**69**	
87	A	Mayo	Duvillaun More	54.074	10.171	6	46	27 Sept	**73**	
88	A	Mayo	Inishkea South	54.115	10.218	6	73	10 Oct	**95**	
88	A	Mayo	Inishkea North	54.136	10.196	6	52	13 Oct	**79**	
88	A	Mayo	Carrickawilt	54.154	10.195	6	6	9 Oct		*
	A	Mayo	Carrigee	54.157	10.195	6	4	9 Oct		*
	A	Mayo	Carrickmoylenacurhoga	54.160	10.188	6	4	9 Oct		*
89	A	Mayo	Inishkeeragh	54.202	10.137	6	8	9 Oct		*
	A	Mayo	Inishglora	54.211	10.129	6	2	9 Oct		**27**
90	B	Mayo	Spinkadoon	54.286	10.025	6	0			
	B	Mayo	Ooghwee	54.296	9.999	6	1	26 Sept		*
91	A	Mayo	Benwee Hd. – west	54.331	9.832	6	5	26 Sept		*
	B	Mayo	Benwee Hd. – east	54.341	9.810	6	0			
	A	Mayo	Doonvinalla	54.338	9.791	6	0			
92	B	Mayo	Corraduff, Claddaghrone	54.337	9.752	6	3	26 Sept		*
	A	Mayo	Pig I.	54.329	9.721	6	0			

Location Number	Category	County	Site/Area name	Lat. °N	Long. °W	No. of surveys	Maximum pup count	Mean birth date	P_i	P_g
93	B	Mayo	Porturlin to Skelp	54.317	9.687	6	6	26 Sept		*
94	A	Mayo	Illanmaster to Belderg	54.325	9.600	6	4	26 Sept		**21**
95	A	Mayo	Carrickneill I. to Minaun	54.320	9.500	6	0			
96	C	**Sligo**	Ballisadare Bay – banks	54.243	8.607	1	0			
97	B	Sligo	Horse I.	54.343	8.677	6	0			
	B	Sligo	Ardboline	54.346	8.693	6	14	9 Oct		*
98	B	Sligo	Inishmurray	54.433	8.660	6	1	9 Oct		**20**
99	C	Sligo	Bomore	54.464	8.674	1	0			
100	A	**Donegal**	St. John's Point	54.568	8.462	6	1	23 Sept		*
101	B	Donegal	Inishduff	54.598	8.546	6	0			
102	A	Donegal	Muckros	54.607	8.584	6	1	23 Sept		*
103	B	Donegal	Rossarrell to Bunglass	54.646	8.719	6	1	23 Sept		*
104	B	Donegal	Rathlin O'Birne I.	54.664	8.827	6	8	23 Sept		*
105	A	Donegal	Malin Bay – skerries	54.671	8.798	6	0			
106	B	Donegal	Oughig to Doon Point	54.706	8.791	6	0			
107	A	Donegal	Glen Hd. to Sturrall	54.730	8.748	6	10	23 Sept		**21**
108	B	Donegal	Sturrall to Glenlough	54.752	8.705	6	41	23 Sept	**59**	
109	A	Donegal	Glenlough to Maghera	54.777	8.609	6	102	25 Sept	**168**	
110	B	Donegal	Inishbarnog	54.813	8.560	6	0			
111	A	Donegal	Roaninish	54.870	8.534	6	0			
112	B	Donegal	Illancrone	54.941	8.480	6	0			
	B	Donegal	Inishkeeragh	54.957	8.495	6	0			
113	A	Donegal	Aran I. – Cronagarn	54.981	8.568	6	21	22 Sept		*
114	B	Donegal	Aran I. – Lighthouse Lot	55.010	8.550	6	10	22 Sept		**29**
115	B	Donegal	Umfin I.	55.102	8.367	6	0			
	A	Donegal	Inishmeane	55.104	8.338	6	0			
	A	Donegal	Inishsirrer	55.120	8.338	6	0			
116	A	Donegal	Inishbofin	55.174	8.172	6	0			
	A	Donegal	Inishdooey	55.193	8.165	6	2	n/d	**3**	
	A	Donegal	Inishbeg	55.204	8.162	6	0			
117	B	Donegal	Tory I. – north	55.270	8.221	4	0			
118	A	Donegal	Tory I. – east	55.257	8.195	4	0			
119	B	Donegal	Pollaguill	55.206	8.019	6	0			
120	A	Donegal	Horn Hd. – west, east	55.221	7.982	6	1	n/d	**1**	
121	B	Donegal	Stowney	55.237	7.838	6	0			
122	C	Donegal	Island Reagh	55.197	7.793	1	0			
123	B	Donegal	Fanad Hd. to Doagh Beg	55.258	7.623	6	0			
124	C	Donegal	Colpaghs Rocks	55.171	7.513	1	0			
125	A	Donegal	Dunaff Hd.	55.285	7.522	6	2	n/d	**2**	
126	C	Donegal	Suil Point to Pollan Bay	55.291	7.412	1	0			
127	A	Donegal	Glashedy I.	55.319	7.399	6	0			
128	C	Donegal	Garvan Is. – Middle I.	55.386	7.313	5	1	n/d	**1**	
129	A	Donegal	Inishtrahull	55.431	7.236	6	2	n/d	**4**	
	C	Donegal	The Tor Rocks	55.446	7.253	1	0			
130	B	Donegal	Esky Bay to Glengad Hd.	55.359	7.242	5	1	n/d	**1**	
131	B	Donegal	Doonglass to Rubonid	55.288	7.110	5	0			
132	B	Donegal	Tremone to Dungloon	55.270	7.031	5	1	n/d	**1**	
	B	Donegal	Ballybane to Inishowen	55.254	6.957	5	0			
133	C	**Dublin**	St. Patrick's I.	53.585	6.074	1	2	n/d	**2**	
	C	Dublin	Colt I.	53.585	6.089	1	0			
	C	Dublin	Shenick's I.	53.572	6.084	1	0			
	C	Dublin	Rockabill	53.597	6.004	1	0			
134	A	Dublin	Lambay I.	53.490	6.020	7	49	25 Sept	56	*
135	A	Dublin	Ireland's Eye	53.406	6.064	7	3	25 Sept		**58**

Location Number	Category	County	Site/Area name	Lat. °N	Long. °W	No. of surveys	Maximum pup count	Mean birth date	P_i	P_g
136	C	Dublin	Dalkey I.	53.272	6.085	1	2	n/d	**2**	
137	A	**Wicklow**	Wicklow Hd.	52.966	6.000	1	1	n/d	**1**	
138	C	Wicklow	Mizen Hd.	52.859	6.057	1	0			
139	C	**Wexford**	The Raven Point - banks	52.333	6.368	1	1	n/d	**1**	
140	A	Wexford	Great Saltee I.	52.117	6.615	8	111	21 Sept	158	*
	A	Wexford	Little Saltee I.	52.137	6.586	8	4	21 Sept		**163**
141	C	Wexford	Keeragh Islands	52.198	6.736	1	0			
142	A	**Waterford**	Swines Hd. to Red Hd.	52.138	7.009	1	0			
143	C	Waterford	Brownstown	52.132	7.088	1	0			
144	C	Waterford	Annestown to Newtown	52.131	7.218	1	0			
145	C	Waterford	St. John's I. to Bunmahon	52.130	7.390	1	0			
146	A	Waterford	Ballyvoyle to Stradbally	52.111	7.481	1	0			
147	C	Waterford	Crobally to Helvick Hd.	52.001	7.583	1	0			
148	A	Waterford	Ardoginna to Ram Hd.	51.939	7.722	1	0			

APPENDIX IV PUP PRODUCTION ESTIMATES FOR SELECTED COLONIES, 1995-2005.

Estimates for a selection of breeding colonies that have been the focus of surveys since 1995. Data generated via Normal and Lognormal birth-distribution plots are shown in addition to minimum productions recorded by through-counting where this method was used. Data sources are shown in Table III. [n/d = not determinable].

County	Breeding colony	Site name	Year	Normal Distribution		Lognormal Distribution		Through-count
				P_i	CV	P_i	CV	P_T
Mayo	Inishkea Group	Keely Island	1995	8	0.20	7	0.27	11
			2002	18	0.14	18	0.22	18
			2005	**43**	**0.10**			
		Duvillaun Beg	1995	n/d	n/d	n/d	n/d	7
			2002	59	0.04	60	0.05	64
			2005	**69**	**0.05**			
		Duvillaun More	1995	52	0.07	52	0.07	60
			2002	75	0.04	75	0.04	92
			2005	**73**	**0.05**			
		Inishkea South	1995	16	0.18	16	0.38	19
			2002	43	0.10	46	0.17	48
			2005	**95**	**0.08**			
		Inishkea North	1995	25	0.22	25	0.22	31
			2002	50	0.07	50	0.07	51
			2005	**79**	**0.08**			
		Carrickawilt to Inishglora	1995	20	0.26	15	0.43	26
			2002	n/d	n/d	n/d	n/d	27
			2005	**27**	**0.14**			
Kerry	Blasket Islands	*all*	1996	135	0.23	135	0.23	155
			2003	190	0.05	190	0.05	
			2005	**185**	**0.06**			
		Beginish	1996	107	0.16	107	0.16	117
			2003	155	0.07	156	0.08	
			2005	**134**	**0.06**			
Wexford	Saltee Islands	*all*	1998	86	0.17	86	0.17	128
			2005	**163**	**0.07**			**178**
Dublin	Lambay Island & Ireland's Eye	*all*	1998	48	0.22	45	0.39	49
			2005	**58**	**0.09**			
Galway	Slyne Head islands	*all*	2004	68	0.25	71	0.19	63
			2005	**68**	**0.12**			