

# An Inventory of Irish Herring Spawning Grounds

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Irish Fisheries Bulletin No. 42, 2013

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June 2013

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Rinville, Oranmore, Co. Galway.

ISSN: 1649 5055

Keywords: Herring, *Clupea harengus*, spawning grounds, larval drift modelling



*CSHMAC*

**This Project was supported by the  
Celtic Sea Herring Management Advisory Committee.**

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## **Abstract**

Atlantic herring, *Clupea harengus*, is an important commercial and forage species in Irish waters. Spawning takes place in coastal waters mostly between September and February in high energy environments, usually at the mouths of bays and estuaries. Herring are benthic spawners and require specific substrate, normally gravel and/or rock, on which to lay their eggs. Because of this reliance, spawning herring can be vulnerable to various anthropogenic activities. It is important to have information pertaining to these sensitive spawning grounds available in the public domain. This is the first study to document all known locations in Irish waters. Available information from previous larval surveys was analysed and a comprehensive fishing industry survey was conducted. A detailed inventory of individual herring spawning beds, grounds and areas around the coasts of the Republic of Ireland was produced. Seabed classification data were consulted to compare the locations of known herring spawning beds with areas consisting of the necessary substrate. There was close agreement in most areas. A larval transport model (LTRANS) was then used to study the predicted dispersal of herring larvae from those areas identified. Preliminary results predict a broadly clockwise dispersal around the coast and that Celtic Sea sites potentially contribute larvae through four ICES management boxes with important implications for fisheries management. This study could be used to assist in future marine spatial planning to ensure that these vulnerable areas are afforded maximum protection.

Keywords: Herring, *Clupea harengus*, spawning grounds, larval drift modelling

## **Introduction**

In Irish waters Atlantic herring, *Clupea harengus* has been exploited for centuries, and continues to be important as a commercial species. In addition, herring is an important forage species and a key element of the marine food web (Townsend 1992). Atlantic herring are benthic spawners (Wheeler 1969) and spawning occurs in discrete beds (Hay *et al.* 2001b) which is uncommon amongst marine fish. Unlike its Pacific congener, *Clupea pallasii*, Atlantic herring tend to rely entirely on a substrate of gravel or rocks on which to deposit their eggs (Townsend 1992).

Spawning grounds in Irish waters are typically located in high energy environments such as the mouth of large rivers and areas where the tidal currents are strong (Molloy 2006). When referring to spawning locations the following terminology, based on Breslin (1998) and Molloy (2006), is proposed:

- Spawning Bed: a discrete spatial unit of sea bed over which herring eggs are deposited, or over which actively spawning herring have been identified.
- Spawning Ground: one or more spawning beds located in a larger spatial unit, enclosing all contiguous potential spawning habitat or substrate type.
- Spawning Area: a number of spawning grounds in a larger geographical region.

The substrate in such beds consists primarily of gravel, stones, broken mussel shell and/or flat rock (Breslin 1998). Herring can form dense spawning aggregations on known spawning beds (Maravelias *et al.* 2000). High fishing mortality can be exerted on these aggregations with little fishing effort. Spawning grounds are also vulnerable to disturbance from deposits of dredge spoil and construction of structures on or over the seabed. These spawning areas may also be of interest as sources of marine aggregate with resultant loss of essential habitat, while re-deposition of finer material

after the extraction may affect a much wider area and cover herring eggs laid on the bottom (de Groot 1996).

Several studies have documented spawning grounds and/or spawning activity around the Irish coast (Grainger 1978; Breslin 1998; Molloy and Kelly 2000). It is important that the geographical location of spawning grounds is available in the public domain as such information can provide a basis for rational decision making in the context of marine spatial planning and fisheries management. This study provides this information for the first time, in a published format.

The purpose of this study was to :

- 1 - Produce an inventory of individual spawning beds, grounds and areas around the coasts of the Republic of Ireland, based on all available information.
- 2 – Predict potential dispersal fields of larval populations from each of these spawning beds.
- 3 - Assess the potential of such grounds to contribute to juvenile and adult herring stocks distal to the natal ground.

In order to protect information that may be commercially sensitive, the geographical coordinates of the individual beds are not presented here. However these data have been archived in a Geographical Information System (GIS) format and are available at a higher spatial resolution for appropriate use.

## **Materials and Methods**

Several approaches were taken to collect and analyse the available information on herring spawning grounds. Available published and unpublished studies were reviewed and interviews of commercial fishermen were undertaken.

### Interviews with fishermen

The interview process was designed, planned and undertaken with the full cooperation of the Celtic Sea Herring Management Advisory Committee (CSHMAC) and fishing industry. A series of interviews were held with experienced herring fishermen, nominated by the CSHMAC, with each having extensive knowledge of targeting spawning herring in a particular coastal area. This information was considered to be reliable, because it was based on experience obtained during the period when fishermen actively targeted spawning fish to obtain roe (eggs). Herring roe was the main marketable product of herring fishing in the late 1980s and 1990s (Molloy 2006). Together, these interviews provided extensive coverage of the Irish coast and the fishing grounds. Data were collected concerning the geographic location of discreet herring spawning beds using Sodena (version 6.0.1.35) software. This allowed for fishing hauls, locations and areas to be recorded and archived. In order to verify the presence of potential spawning grounds each fisherman was invited to describe the necessary requirements for a herring spawning bed and to discuss each in as much detail as possible. A confidentiality agreement was signed to ensure that the exact coordinates of commercially sensitive fishing grounds were not disseminated. Following the convention of Breslin (1998), individual spawning beds were grouped into spawning grounds which in turn were grouped into spawning areas.

### Other information on spawning locations

In addition to the industry survey, literature sources (Grainger 1980; Anon. 1994; Breslin 1998; Molloy and Kelly 2000) were consulted and any relevant information was extracted. Grainger (1978;1980) described the abundance and distribution of early herring larval stages in both Galway Bay and the Celtic Sea. Herring spawning beds and grounds were broadly identified by Breslin (1998). Molloy and Kelly (2000) summarised the state of the herring stock to the northwest of Ireland, while also identifying some of the more important spawning, nursery and feeding grounds in conjunction with local fishermen. Further information on larval distribution was available from analysing previous larval surveys in the Celtic Sea from 1978-1985 and 1989-1990 (Grainger, unpublished data) and the Northwest coast from 1981-1988 (ICES Herring Larval

Database). The data collected consisted of the abundance ( $m^{-2}$ ) of herring larvae within different size classes (<10mm, 10-16mm and >16mm); their geographic distribution; the time and date of each haul per survey and the depth at which it was conducted. Following Blaxter (1990), the age of herring larvae was inferred from the length in mm. Larvae measured at <10mm are assumed to be not more than 14 days old and likely to be closest to the site of origin. The abundance of larval size classes was mapped in ArcMap 10. To collate and cross-reference both the interview data and the previous studies, any available spatially resolved data were georeferenced using a Geographic Information System (ArcMap 10). This allowed for a digital inventory to be created, containing shapefiles as data layers, representing specific information. The inventory contained the geographic coordinates for all known spawning beds/grounds and areas as described from both previous scientific studies and contemporary industry surveys together with any further supplementary information. The spatial extent of the individual spawning beds could then be measured and analysed.

#### Hydrodynamic and particle-tracking model

In order to determine the likely dispersal fields of larvae from the various spawning grounds a larval transport model, LTRANS, was used. The model was initially developed by the University of Maryland to track oil-spills and was modified to track the dispersal of oyster larvae through Chesapeake Bay, USA (North *et al.* 2008). In the present study LTRANS calculates the movement of particles that simulate herring larvae. The trajectories were modelled in three-dimensions enabling predictions about the extent of the dispersal field. Trajectories were forced by the stored environmental predictions of a hydrodynamic model based on 2011 and 2012 data, here the Regional Ocean Modelling System (ROMS). The model assumed open water turbulence in both planes and further assigned a constant value for random horizontal diffusion at  $1m^2/sec$ . Elementary behaviour was ascribed to the particles to determine the effect of growth and larval swimming behaviour on dispersal distance. Various model runs were conducted to study the dispersal from individual herring spawning. 10 000 particles were released in accordance with peak spawning times for each bed and tracked for 4 months.

### Physical parameters

LTRANS was designed to predict the movement of particles based on advection, turbulence and swimming behaviour. It includes an external time-step of model output and an internal time-step of particle movement. The external time step is the time step of hydrodynamic model output. This is set in the present study at 10 800 seconds as hydrodynamics are archived every 3 hours (3\*3600). The internal time step is the time interval during which particle movement is calculated. The internal time step is smaller than the external time step to allow particles to move in smaller intervals than the hydrodynamic model output intervals as large jumps could cause inconsistencies between predictions. This study used an internal time step of 500 seconds which offers a compromise between acceptable run-time and ensuring that each time-step occurs within the appropriate grid cell. The resolution of the grid cells within the model are approximately 1.5km x 1.5km, with 40 vertical sigma-levels.

Boundary conditions were imposed such that if a particle passed through a vertical (ie. seabed or sea-surface), or horizontal boundary (at the grid cells specifying the land-sea interface), it was reflected at an angle equal to the angle of approach and at an equal distance to that which it originally passed the boundary or, if stipulated, remained on the boundary (see Figure 1). A complete description of model functionality and design parameters of LTRANS v.2 are given by Schlag and North (2012) and North *et al.* (2008).

### Behavioural parameters

In order to simulate 'living' larvae, a simplified behavioural model was used to differentiate between the advection by passive drift and active swimming. Behaviour was parameterised from previous field and laboratory studies which describe the early life-stages of herring (see Townsend 1992; Heath *et al.* 1988 and Blaxter 1990). The length of time the larvae spend drifting with the prevailing currents varies depending on the date of their birth. Herring larvae are expected to develop swimming behaviour after about 30 days or once suitable feeding commences (Townsend 1992). Passive drift ends and swimming starts with the onset of the planktonic spring bloom for spring

spawners. This study considered this date as the 1<sup>st</sup> of March for all scenarios and a linear increase in swim speed was applied up to 5 mm/s. Table 1 shows the biological and physical characteristics used within the model.

#### Seabed habitat data

Seabed habitat data were available from two sources; firstly the INFOMAR programme - Integrated Mapping for the Sustainable Development of Ireland's Marine Resource (2005–present), formally Irish National Seabed Survey (INSS, 2000-2005) and secondly, from data collated by the MeshAtlantic Project. INFOMAR is a joint venture between the Geological Survey of Ireland and the Marine Institute and concentrates on mapping the seabed in near-shore areas using data collected by multibeam echosounder data (MBES). The main objective of MeshAtlantic project is to collate disparate sources of seabed habitat maps to produce a single, harmonised, EUNIS (European Nature Information System) habitat map for the Northeast Atlantic.

MBES systems use sonar technology to transmit a broad acoustic, fan shaped, pulse from the vessel to the seabed which provide information on the bathymetry and the nature of the seabed which can be used to interpret the substrate type present. The INFOMAR project has produced a series of substrate maps that classifies sediments using the amplitudes and statistical properties of the backscatter images. The resulting classifications using this technique were unsupervised, i.e. sediment descriptions were based on acoustic properties only. Physical sampling undertaken by the project was used to verify the substrate maps produced. All sediment samples were subject to Particle Sediment Analysis (PSA), which determined the relative proportions of various particle size fractions per sample, and groups them into one of 15 Folk classes.

Physical habitat maps delivered by INFOMAR, together with habitat maps and other data from Bord Iascaigh Mhara, National Parks and Wildlife Service, Coastal and Marine Research Centre and Joint Nature Conservation Committee, were collated as part of the MeshAtlantic project. All were standardised by translating the original classifications assigned to the habitat maps to a EUNIS (European Nature Information System) classification (Davies *et al.* 2004) in order to create a single, harmonised

habitat map for the Irish EEZ. The resulting map was classed to EUNIS level 4 displaying 8 physical habitat classes; rock, coarse sediment, mixed sediment, sand, muddy sand, sandy mud, mud and macrophyte-dominated sediment. The rock class in this classification system encompassed small stones, pebbles, boulders and bedrock.

## **Results**

### Information from the fishing industry

Eight interviews were conducted in 2012 in Castletownbere, Baltimore, Schull, Rossaveal, Duncannon, Dunmore East, Dingle and Galway. On average the interviewees had been fishing herring for 30 years and were able to provide extensive detail on the temporal and spatial movement of spawning herring aggregations. Six interviews dealt with fishing grounds in the Celtic Sea while the remaining two covered the entire west, south and north coasts. Interviewees were invited to provide as much relevant information about each spawning bed as possible. This included its geographic location, size, depth, commercial importance, the time of peak spawning activity and the historical significance as well as any additional supplementary information. Each interviewee was asked to describe certain conditions that indicated the presence of spawning herring aggregations. These included the presence of aggregations of dense, conical shaped schools upon the sea-floor as revealed on an echo-sounder and/or the presence of broken rock or gravel substrate, known colloqually as 'hard shade'. Captured fish were staged as spawning by expressing roe, upon slight compression of the belly (known as 'running roe'). This is consistent with maturity stage VI (Landry and McQuinn 1988).

In total 87 separate spawning beds were described within 51 spawning grounds. These were then grouped into 13 major herring spawning areas covering Irish coastal waters. There are 5 such areas off the north coast and 8 in the Celtic Sea. These areas and grounds have been arbitrarily grouped according to geographic locations following Farran's (1944) review (Figure 1). Higher resolution maps of the location of spawning beds, grounds and spawning areas (following Breslin 1998) with available Mesh Atlantic

supervised seabed habitat data are provided in Figure 2. Available seabed data from the INFOMAR programme are shown in in Figure 3.

All the beds identified consisted of gravel/broken rock substrate except one small sandy area in Baltimore harbour. The beds ranged in depth from 7 to approximately 90 m. Spawning grounds are generally deeper off the north coast and located further off-shore than in the southern area. North coast grounds were up to 80m deep. In the Celtic Sea the average spawning bed depth was at ~30m depth, no more than 2 miles from the coast and often located within bays and estuaries.

The reported size of each individual spawning bed also varied considerably. The smallest grounds were found predominately in the Celtic Sea, where nine were not larger than 0.1 km<sup>2</sup>. The smallest was an area of 0.01 km<sup>2</sup> near Crookhaven in a depth of 18 m. The largest bed in the Celtic Sea is 36 km<sup>2</sup> in the Dunmore East area. In contrast beds in the north and northwest were considerably larger, the largest being nearly 170 km<sup>2</sup> near the Limeburner Rock, off north Donegal. Table 2 provides all available relevant information on each spawning bed described including depth (m) and area (km<sup>2</sup>).

The time of reported peak spawning activity varied from site to site between September and February/March. The period over which this activity was reported to occur ranged from weeks to months. Eleven sites have been observed by fishermen to have two distinct spawning seasons with an intervening lull period. These seasons are generally two months apart: September/December; October/January and November/February. Many of the sites have had a reported decline in the abundance of spawning herring since 1995 and are not commercially important anymore. Spawning in the Celtic Sea is reported to occur in sequential waves with fish approaching the coast near Cork in October, with activity peaking in November (Figure 4). The herring spawning activity then slowly occurs more eastwards, occurring in or around Dunmore East in December and January. Many of the larger commercially important grounds in the Celtic Sea were well described independently by numerous sources providing further validation of their importance. Despite, this seperate beds and favoured trawl tracks were often described within each ground. This was

especially true of Kerry Head and the Daunt grounds. Two sites were only described by a single interviewee. In the northwest this localised knowledge was less apparent and the larger spawning areas were widely known.

#### Previous larval studies

The distribution of herring larvae off the Irish coast as derived from previous herring larval surveys is presented in Figure 5. Annual abundance for three herring larvae size classes (<11mm, 11-16mm and >16mm) is grouped here by month. Celtic Sea survey data (1978-1985, 1989-1990) (Grainger, unpublished) exist for September – March and the ICES Herring Larvae Database (1981-1988) contains data for September – November.

#### Larval modelling

Larvae dispersal modelling results showed a primarily clockwise dispersal around the coast. For those sites with two separate spawning events, a simulation was conducted during the month of each event to study if dispersal differs from month to month. The five spawning areas in Figure 6 represented a broad coverage of Irish coastal waters and the predicted dispersal from adjacent sites is similar. In all cases larvae were dispersed to areas outside of the spawning area as expected (Table 3). Larvae in the northwest are broadly transported “clockwise” around the coast towards the Clyde (VIaN) and in many cases into the Irish Sea. In the Celtic Sea larvae were dispersed widely. The spawning beds off south Cork have the largest potential dispersal field and may contribute larvae to any other herring spawning areas identified in this study, including into ICES Division VIaN and the Firth of Clyde. Dispersal from Dunmore East was predicted to be both into the Irish Sea to VIIaN/VIIb and into the Celtic Sea spanning the East Cork, Daunt and South Cork areas. A selected comparison of potential larval dispersal using LTRANS and observed larval distribution from previous surveys is provided in Figure 7.

#### Seabed mapping

Figure 2 shows the spawning areas and the individual spawning beds in conjunction with MeshAtlantic supervised seabed classification data. In Figure 3 classified seabed survey data from the INFOMAR programme are provided for Donegal Bay, Galway

Bay, Bantry Bay, Cork Harbour and Waterford/Wexford along with herring spawning beds. Any overlap between these locations and suitable substrate upon which the fish can spawn are shown.

## **Discussion**

Many aspects of the biology of Atlantic herring have been well studied in Ireland yet information on the location of spawning beds is not readily accessible. Given the importance of the herring fishery and herring's role as a forage fish, it is prudent to document the location of all such areas.

The increased demand and premium prices for herring roe resulted in target fisheries on spawning herring (Molloy 2006). As a result, hitherto poorly known areas subsequently became well known within the industry. For this reason, these interview data are considered to be a reliable basis for identifying the spatial distribution of spawning grounds. The spawning beds, grounds and areas presented in this study were identified and described by experienced herring fishermen familiar with the herring roe industry. While every effort was made to confirm the precise locations of the spawning beds there is the potential for some error in the collation of fishermen's information. However the multiple interviews conducted constitute a form of extended peer review of the information, and each of the fishermen interviewed had knowledge of multiple beds around the coast. Positional data was verified across the interview process.

There are many activities that may impact on herring spawning beds. These include dumping of dredge spoil, aggregate extraction and construction of structures on or over the seabed. Activities adjacent to, though not actually upon a spawning bed may also be deleterious. For instance, a turbid water column saturated with particulate matter may cover and damage herring eggs (de Groot 1996). In addition, the discrete nature of these beds means that spawning schools are vulnerable to fisheries, and high fishing mortality may be expended with little effort. Catastrophic accidents may also have negative impacts on spawning beds. As an example, in 1986 the bulk-carrier, *MV Kowloon Bridge*, sank in the vicinity of the Stags of Baltimore, a well-known herring

spawning ground spilling its cargo of iron-ore over the seabed. No herring spawning activity has since been reported on these beds. Instead the fish may have availed of an alternate proximal ground on which to spawn thereby leading the fishing fleet to a previously unused, or unexploited, spawning ground.

Data from seabed mapping surveys show the location and extent of different sediments and constitute a useful resource in verifying information provided by the industry survey. The sediment maps show that all spawning beds identified by fishermen occur on gravel/broken rock and in one instance sand. The study highlights that the full extent of potential habitat is much larger than the actual spawning grounds. This is especially true in the northwest. Why only some of this physical habitat is persistently used is unclear and there are probably alternative habitat cues used by herring which are not characterised by the acoustic backscatter data.

It should be noted that the larval dispersal modelling in this study was conditioned on environmental data from 2011 and 2012 and may not represent the full range of environmental conditions experienced in all years by herring larval populations. Results from the larval transport model indicate that herring larvae in Irish waters follow a broadly clockwise movement around the coast after hatching. This is in agreement with predictions of the prevailing current (Fernand *et al.* 2006). In contrast, Ozcan (1974) proposed that herring larvae originating in the eastern Irish Sea would move in an “anti-clockwise” dispersal into the Irish Sea. Evidence from the present study suggests that this may only be the case during winter months at some spawning areas, especially Dunmore East.

Analysis of previous larval surveys showed highest densities of early stage larvae (<11mm) in the vicinity of spawning grounds identified in this study. In October/November these larvae were found in large numbers near Dunmore East, the Daut and North Kerry. These areas were identified as key sites for early winter spawners. Middle/late stage larvae were generally more abundant in December and found along the southeast coast reflecting the dispersal of larvae as they grow. This trend was repeated in January as spawning peaks in Dunmore East. Early stage larvae are most abundant here at this time but are replaced by larger larvae (>16mm) by

March. This distribution of early stage larvae from previous surveys reflects the same pattern of dispersal as predicted here and suggests that the predicted larval dispersal fields reflect the general pattern of dispersal of herring larval populations off the Irish coast.

Celtic Sea sites generally had the largest dispersal fields. The predicted larval dispersal suggests an open population structure, with movement of larvae from each spawning bed to many other areas. This may have implications for fisheries management and the relevance of some ICES divisional boxes, as an example it is predicted that the Scottish Firth of Clyde is a recipient of herring larvae from 8 Irish spawning areas, which encompass separate fishery management units.

The timing of spawning has an important influence on the ultimate distribution of herring larvae. A larger dispersal field, probably influenced by stronger current and wind forcing (Fernand *et al.* 2006), is generally observed for larvae hatched in October and November than in those hatched in January and February.

Although the output of the larval dispersal modelling agrees well with previous observations on the distribution of different size classes of larvae and dispersal fields, the parameterization of the larval behaviour could be improved. For example, vertical migration based on photoperiod should be considered in further modelling to account for a daily migration of larvae through the water column that takes advantage of more advantageous feeding conditions by day in the upper 20m (Townsend 1992). Furthermore, a mortality function can be modelled as a knife-edge process at the end of the simulated larval trajectory whereas mortality would better be modelled as an exponential decay process throughout dispersal.

This study is the first to show the locations of all herring spawning grounds in coastal waters of the Republic of Ireland. The results are based on extensive knowledge held within the fishing industry and validated with seabed data available from the national seabed survey programme. Larval modelling provides a first estimate of the spatial extent of larval dispersal fields from spawning beds which correspond with observed larval distributions from previous surveys. These results can be used for the purposes of marine spatial planning and to avoid negative impacts on herring spawning grounds.

It is not possible to ascertain the contribution of individual spawning beds to recruitment of herring stocks. But to follow the precautionary approach it is necessary that all known beds are afforded maximum protection. The importance of herring as a forage fish (Blaxter 1990), and as a commercial resource (Breslin 1998) relies on favourable recruitment and the loss of spawning beds should to be avoided.

## **Acknowledgements**

This project was financed by the Celtic Sea Herring Management Advisory Committee (CSHMAC). We would like to thank Gavin Power (CSHMAC), Martin O’Conghaile, Pauric Connelly, Tom Kennedy, Anthony Sheehy, Frankie Griffen, Richard Power and Michael Foley for their contribution to this project. We would also like to thank Glenn Nolan (MI Oceanographic Services and LTRANS) and Fergal McGrath (Advanced Mapping Services and Infomar) both groups being within Ocean Sciences Information Services (OSIS) at the Marine Institute. Additional data contributors of collated habitat mapping are Geological Survey of Ireland, EMODnet, HabMap & Irish Sea Pilot Mapping Projects, Bord Iascaigh Mhara, National Parks and Wildlife Service, Coastal and Marine Resource Centre (UCC), Joint Nature Conservation Committee.

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**Table 1.** Variable biological and physical LTRANS parameters used during the present study (see also Schlag and North 2008).

<b>Biological Characteristics</b>		<b>Physical Characteristics</b>	
No. Of Particles	10,000	Boundary	False
Larval Release	1 <sup>st</sup> March	External time-step	10800 sec
Maximum Swim Speed	5 mm/s	Internal time-step	400 sec
Mortality	95%	Horizontal Turbulence	True
Larval Duration	4 months	Vertical Turbulence (1m <sup>-2</sup> /s)	True

*An Inventory of Irish herring spawning grounds*

**Table 2.** Spawning areas, spawning grounds and spawning beds around the Northwest coast. Area (km<sup>2</sup>) and depth (m) refer to individual spawning beds.

Spawning Area	Spawning Ground	Spawning Bed	Depth (m)	Area (Sq Km)	Activity
<b>North Donegal</b>	Malin Head	Inishtrahull	45	121.58	November
		Malin Head North	90	39.06	November
	Limeburner	Limeburner	30	33.28	November
		The Bananas	58	169.17	Nov and Feb
	Tory	Malin Head Northwest	70-90	47.42	Nov and Feb
<b>West Donegal</b>	The Blowers	The Blowers	30	3.96	Oct/Nov
		Stags	20	0.89	Nov/Dec
	Aran Mor	Aran Mor I	43	32.35	Oct/Nov
		The Quarry	70-80	11.84	October
	Rosbeg 1	Rosbeg 1.1	32-36	0.13	Oct/Nov
	Rosbeg 2	Rosbeg 2.1	43	44.06	October
	Glen Head	Glen Bay	32-36	24.17	Nov/Dec
		Malinmore Head 1	18	6.31	November
		Malinmore Head 2	90	1.59	Jan/Feb
<b>Donegal Bay</b>	Killybegs	Killybegs I	20	1.01	Dec/Jan
	Lennadoon	Lennadoon I	32-42	101.92	Jan/Feb
		Killala Bay	25	3.05	January
	Downpatrick	Downpatrick West	32	23.66	November
		Downpatrick/Ceide Fields	34-45	97.05	Dec/Jan
<b>Mayo</b>	The Stags	The Stags I	36	0.89	November
	Blackrock	Blackrock I	36	7.74	Oct/Nov
	Clare Island	The Bills	36	29.83	November
		Clare Island I	32	3.07	Oct/Nov
		Clare Island 2	36	1.58	Oct/Nov
		South Clare Island I	45	3.71	December
		South Clare Island 2	~40-45	2.01	Nov/Dec
	Lecky Rock	Davillaun/Lecky Rock	20	3.63	Sept/Oct
<b>Galway</b>	Croaghnaकेela	Croaghnaकेela I	27	0.33	Nov/Dec
	Namackan Rock	Namackan Rock I	10-30m	0.84	November
	Casla Point	Keeran Bay	Jan-00	5.02	Oct/Nov
		Casla Point I	30-36	14.82	Oct/Nov
	Inishmor	Dun Aengus	36	3.1	October
		Inishmor I	30-35	8.65	Oct/Nov
		Kilronan	30	0.79	Nov/Dec
	Inishman	Curran Banks	32	1.68	Oct/Nov
		Inishman I	28-32	0.55	Nov/Dec
	Kilstiffin Rocks	Kilstiffin Rocks I	32	1.13	Sept/Oct

**Table 2 continued.** Spawning areas, spawning grounds and spawning beds around the Celtic Sea and southwest coast. Area (km<sup>2</sup>) and depth (m) refer to individual spawning beds.

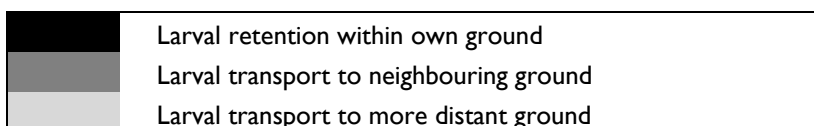
Spawning Area	Spawning Ground	Spawning Bed	Depth (m)	Area (Sq Km)	Activity
<b>North Kerry</b>	Kerry Head	Kerry Head 1	27-30	3.1	Oct/Nov
		Kerry Head 2	25-30	1.7	Oct/Nov
		Kerry Head 3	25-30	6.86	Oct/Nov
		Brandon Head	~50	2.87	October
	Smerwick Harbour	Smerwick Harbour 1	30	0.91	November
	The Blaskets	The Blaskets 1	45	3.68	Sept/Oct
	Slea Head	Slea Head 1	32-35	4.22	Oct/Nov
<b>South Kerry</b>	South Dingle Bay	South Dingle Bay 1	35	9.39	Oct and Jan
	Scariff	Scariff	30-32	2.97	Oct and Jan
<b>West Cork</b>	Kenmare Bay	Kenmare Bay	20-25	0.5	January
	Garnish Island	Garnish Island	32-36	5.23	Oct/Nov
	Durseley Island	Durseley North	~36	1.97	October
		Durseley South	40-54	1.82	Oct/Nov
	Pulleen	Pulleen 1	36	2.76	Oct/Nov
	Gerahies	Gerahies 1	18-25	4.88	Oct and Jan
Sheeps Head	Sheeps Head 1	32-35	1.56	Oct/Nov	
<b>Roaringwater Bay</b>	Brow Head	Bird Island	30-45	1.7	Oct/Nov
		Devil Rock	7-10m	0.03	Sept/Oct
		Brow Head 1	30	8.92	Oct/Nov
	Crookhaven	Crookhaven 1	18-29	0.02	Oct/Nov
		Crookhaven 2	15-18	0.01	Oct/Nov
	Golleen Bay	Golleen Bay 1	18-27	0.04	Nov and Feb
		Golleen Bay 2	18-25	0.04	Oct/Nov
		Golleen Bay 3	20-27	0.03	Nov and Feb
		Goat Island	15	0.04	Nov/Dec
	Baltimore	Baltimore 1	3-10m	0.03	October
Sherkin Pier		5-10m	0.03	October	
<b>South Cork</b>	The Stags	The Stags 1	31-36	0.07	Oct/Nov
		The Stags 2	35	0.07	October
		The Stags 3	31-36	0.13	Oct/Nov
	High Island	High Island 1	12-21m	0.14	Oct/Nov
	Galley Head	Galley Head 1	15-20	0.8	Oct/Nov
	Horse Rock	Horse Rock 1	14-18	0.02	Sept and Dec

**Table 2 continued.** Spawning areas, spawning grounds and spawning beds around the Celtic Sea and southwest coast. Area (km<sup>2</sup>) and depth (m) refer to individual spawning beds.

Spawning Area	Spawning Ground	Spawning Bed	Depth (m)	Area (Sq Km)	Activity
Daunt	Holeopen Bay	Holeopen Bay I	18-25	0.33	October
	Daunt 1	Daunt 1.1	15-35	0.24	Nov and Feb
		Daunt 1.2	15-35	0.22	February
	Daunt 2	Daunt 2.1	20-35	1.01	Oct/Nov
		Daunt 2.2	30	2.36	February
	Daunt 3	Daunt 3.1	20-30	0.22	Nov/Dec
The Smiths		21-25	0.53	February	
East Cork	Ballycotton	Ballycotton I	20-30	0.41	November
	Youghal	Youghal	15	0.61	October
	Rams Head	Rams Head I	20-25	1.17	Nov and Feb
Dunmore East	Tramore	Brownstone	15-20	10.89	Jan/Feb
		The Roads	35	5.24	Dec/Jan
	Baginbun	Hook Head	25-35	15.06	December
		The Big Rock	30	1.72	December
		Baginbun I	20-30	11.83	October
	Keeragh Island	Keeragh Island I	36	36.07	Sept/Oct

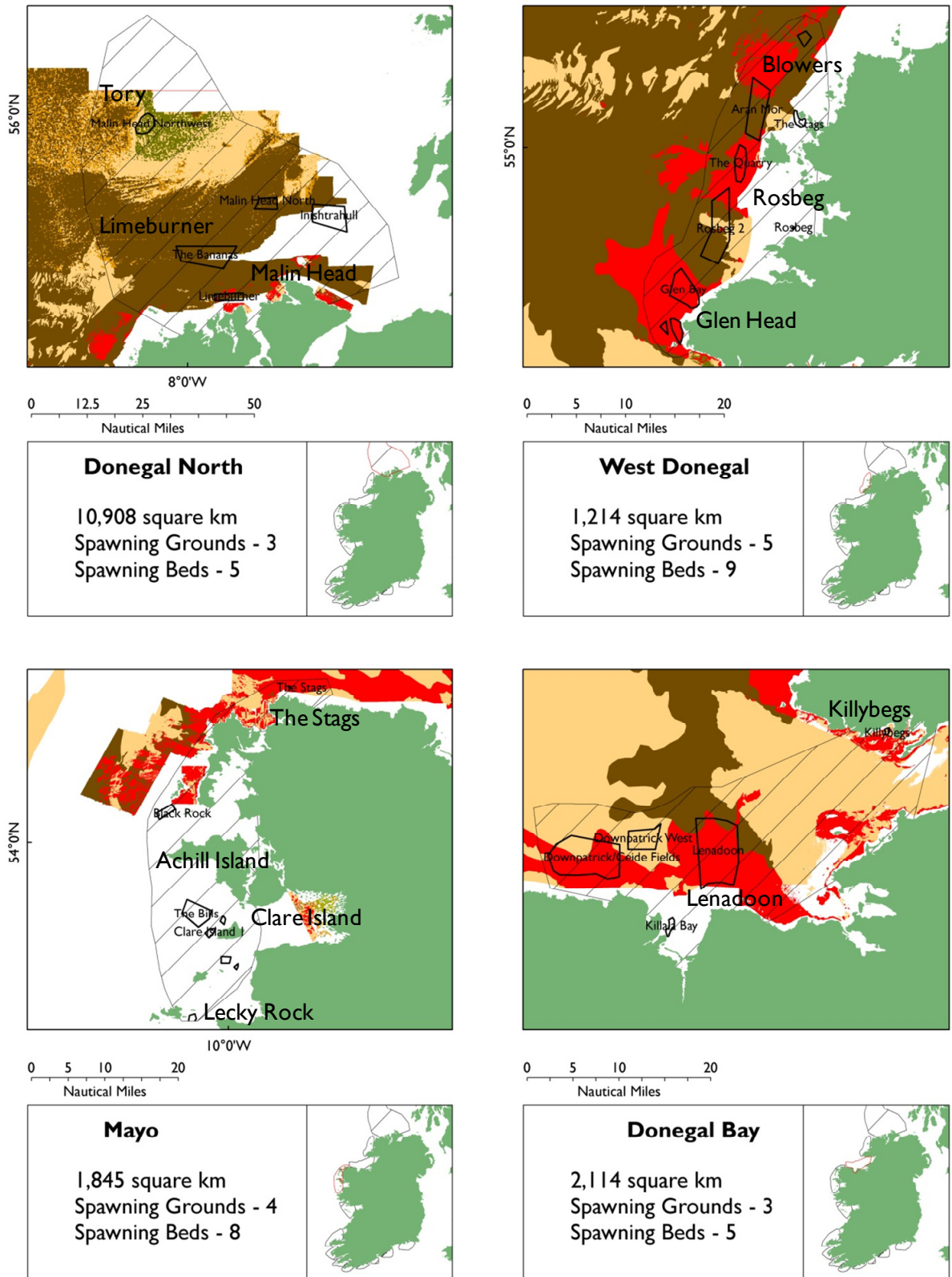
**Table 3.** Potential larval dispersal field , from Irish herring spawning areas. Larvae were tracked with LTRANS using simulated hydrodynamic conditions from October 2011 – February 2012. All areas contributed larvae to at least one other spawning area (dark grey shading). Light grey shading represents dispersal to more distant areas. Shading both above and below the diagonal shows dispersal can potentially be both “clockwise” and “anti-clockwise” around the Irish coast. A complete shading would represent a fully extensive dispersal field e.g.. South Cork. The Firth of Clyde (Scotland), is a predicted recipient of herring larvae from 8 herring spawning areas in the Republic Of Ireland.

ICES area		VlaN	VlaN (Clyde)	VlaS	VlaS	VlaS.VIIb	VIIb	VIIb	VIIj	VIIj	VIIj	VIIj	VIIj	VIIj	VIIg	VIIg	VIIaS	VIIaN	VIIIf
	Spawning Area	-	-	N. Donegal	W. Donegal.	Donegal Bay	Mayo	Galway	N. Kerry	S. Kerry	W. Cork	Roaringwater Bay	S. Cork	Daunt	E. Cork	Dunmore East	-	-	
VlaN	-	■																	
VlaN (Clyde)	-		■																
VlaS	N. Donegal			■															
VlaS	W. Donegal.				■														
VlaS.VIIb	Donegal Bay					■													
VIIb	Mayo						■												
VIIb	Galway							■											
VIIj	N. Kerry								■										
VIIj	S. Kerry									■									
VIIj	W. Cork										■								
VIIj	Roaringwater Bay											■							
VIIj	S. Cork												■						
VIIg	Daunt													■					
VIIg	E. Cork														■				
VIIaS	Dunmore East															■			
VIIaN	-																■		
VIIIf	-																	■	





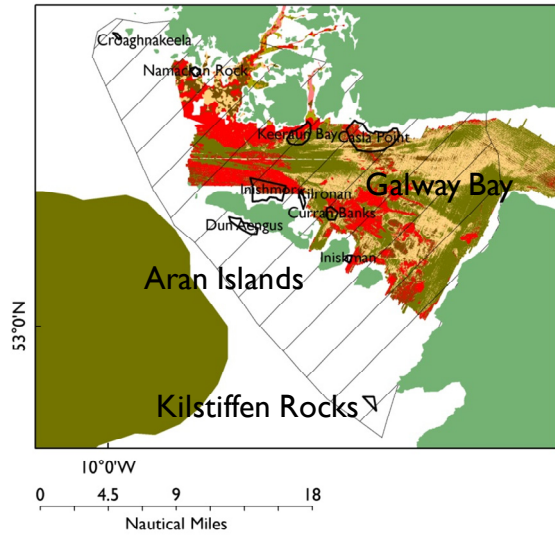
**Figure 1.** Herring spawning areas (named) and spawning grounds (pink) around the coast of the Republic of Ireland identified in this study and presented following Farran (1944). Locations mentioned in text are included. Spawning grounds in close proximity are merged where there is continuity of potential herring spawning habitat. Inset – extent of LTRANS boundary domain and ICES divisional boxes.



**Seabed Classification**

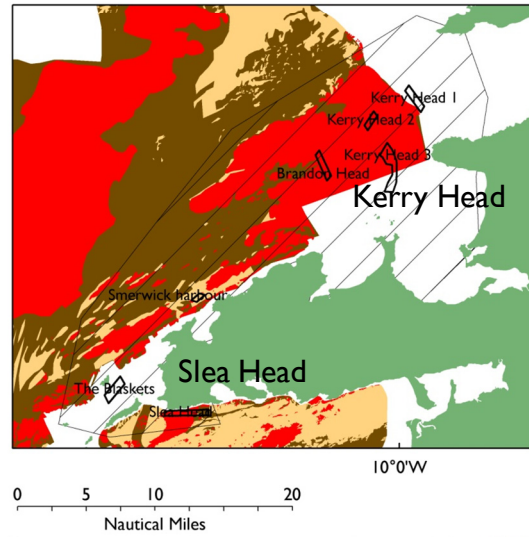
- Rock
- Mixed sediment
- Muddy sand
- Mud
- Coarse sediment
- Sand
- Sandy mud
- Macrophyte-dominated sediment

**Figure 2.** Herring beds and herring grounds (named only) within each main spawning area. The area (km<sup>2</sup>) of each spawning area and the number of beds and grounds within is indicated, along with available supervised seabed classification data collated by MeshAtlantic. These data have been translated to a EUNIS classification system following Davies *et al.* (2004).



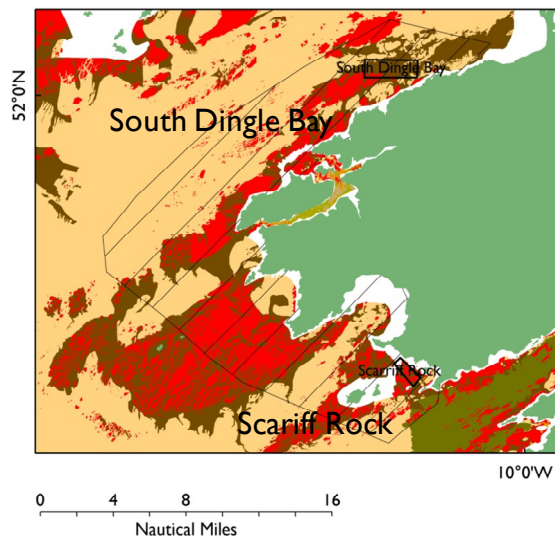
**Galway**

1,521 square km  
 Spawning Grounds - 6  
 Spawning Beds - 10



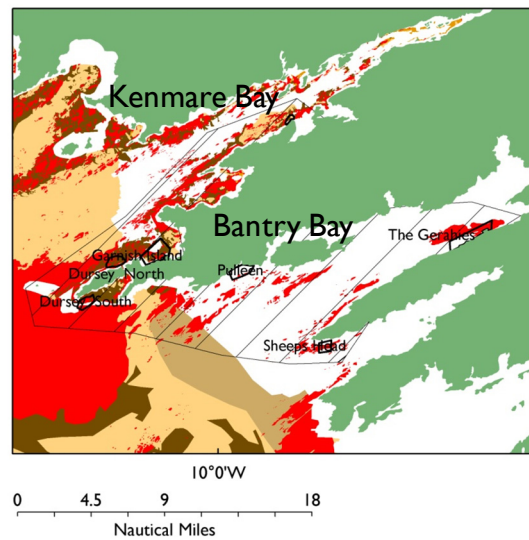
**North Kerry**

1,508 square km  
 Spawning Grounds - 4  
 Spawning Beds - 7



**South Kerry**

724 square km  
 Spawning Grounds - 2  
 Spawning Beds - 2



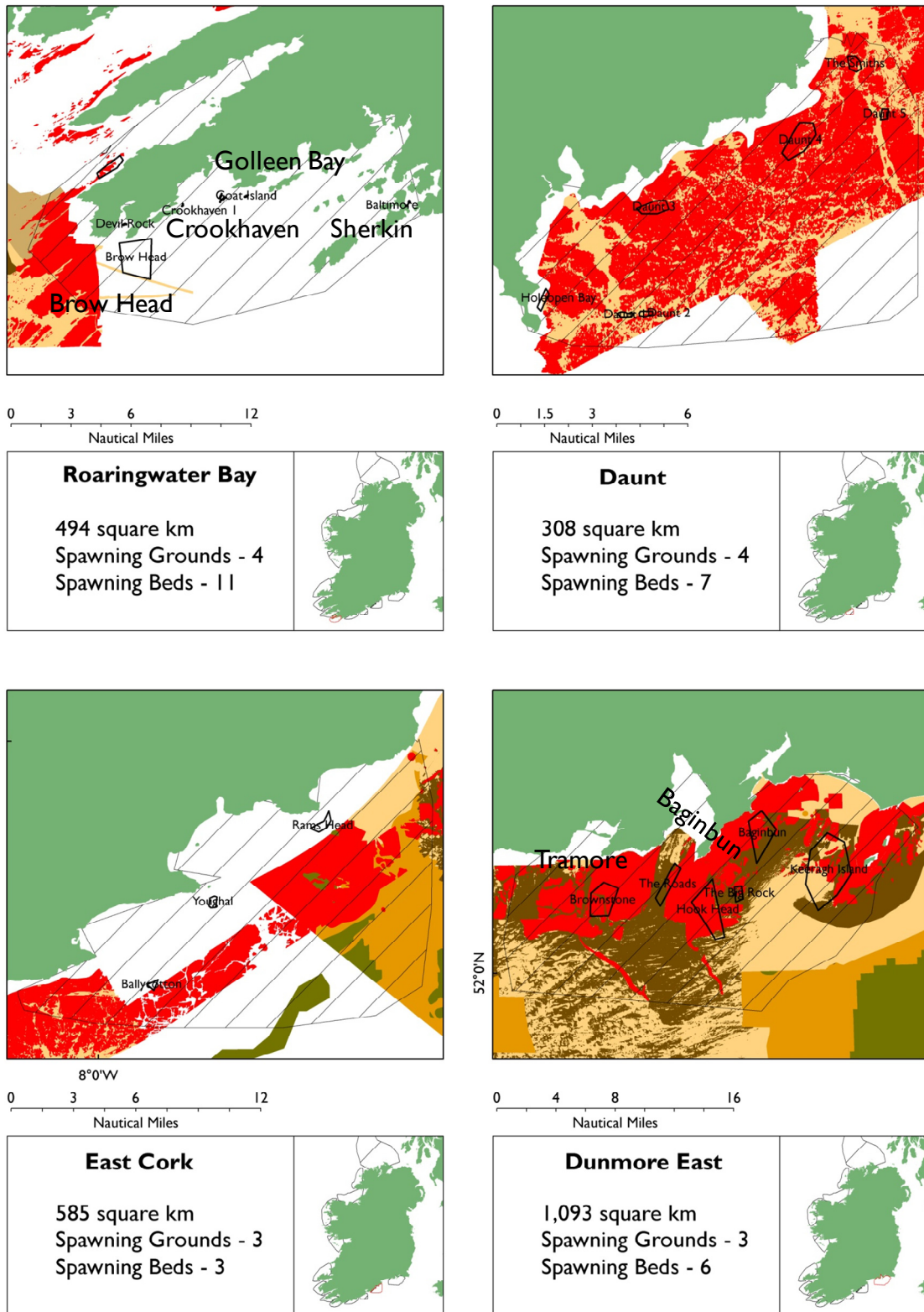
**West Cork**

710 square km  
 Spawning Grounds - 6  
 Spawning Beds - 7

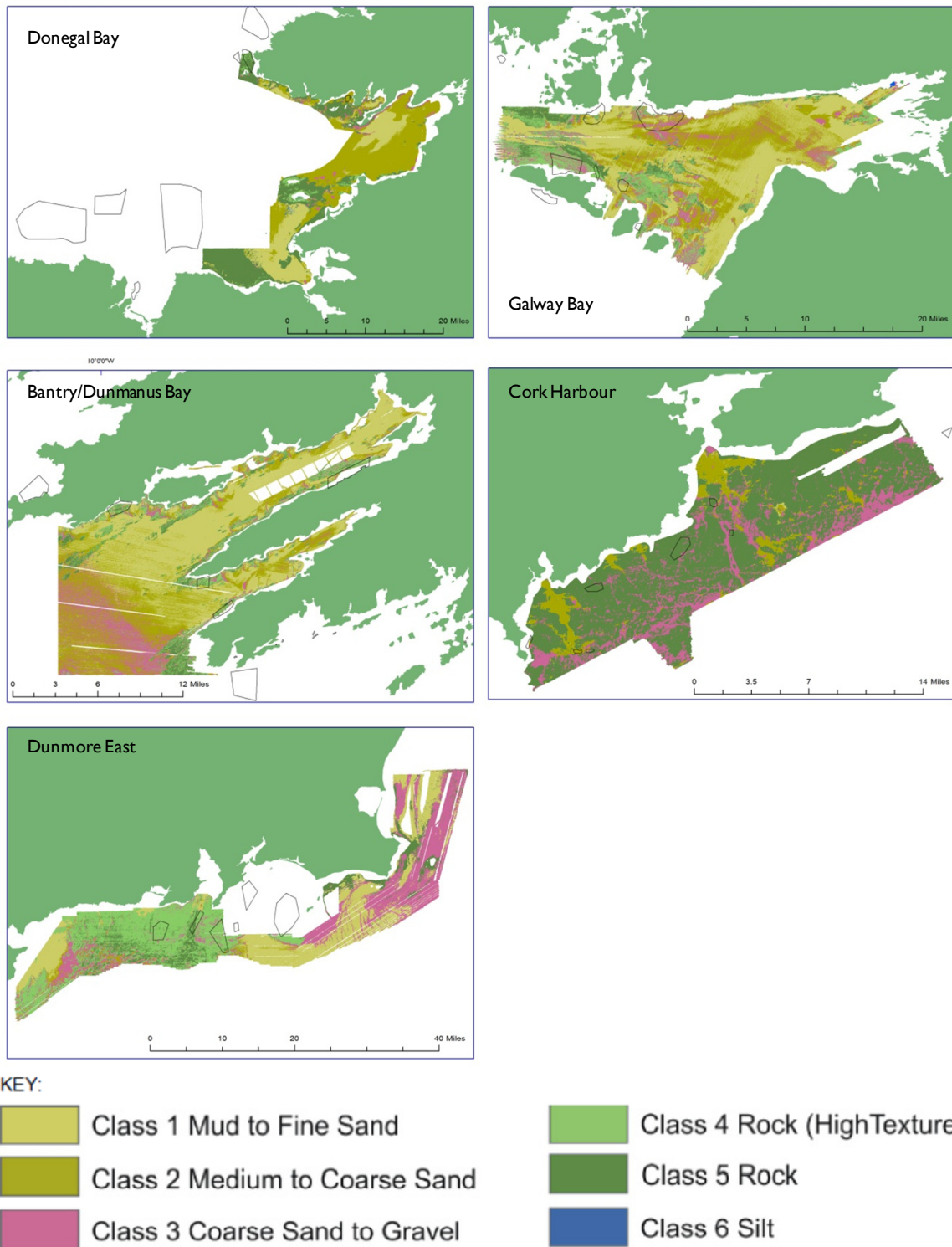
**Seabed Classification**

- Rock
- Mixed sediment
- Muddy sand
- Mud
- Coarse sediment
- Sand
- Sandy mud
- Macrophyte-dominated sediment

**Figure 2 Continued.** Herring beds and herring grounds (named only) within each main spawning area. The area (km<sup>2</sup>) of each spawning area and the number of beds and grounds within is indicated, along with available supervised seabed classification data collated by MeshAtlantic. These data have been translated to a EUNIS classification system following Davies *et al.* (2004).



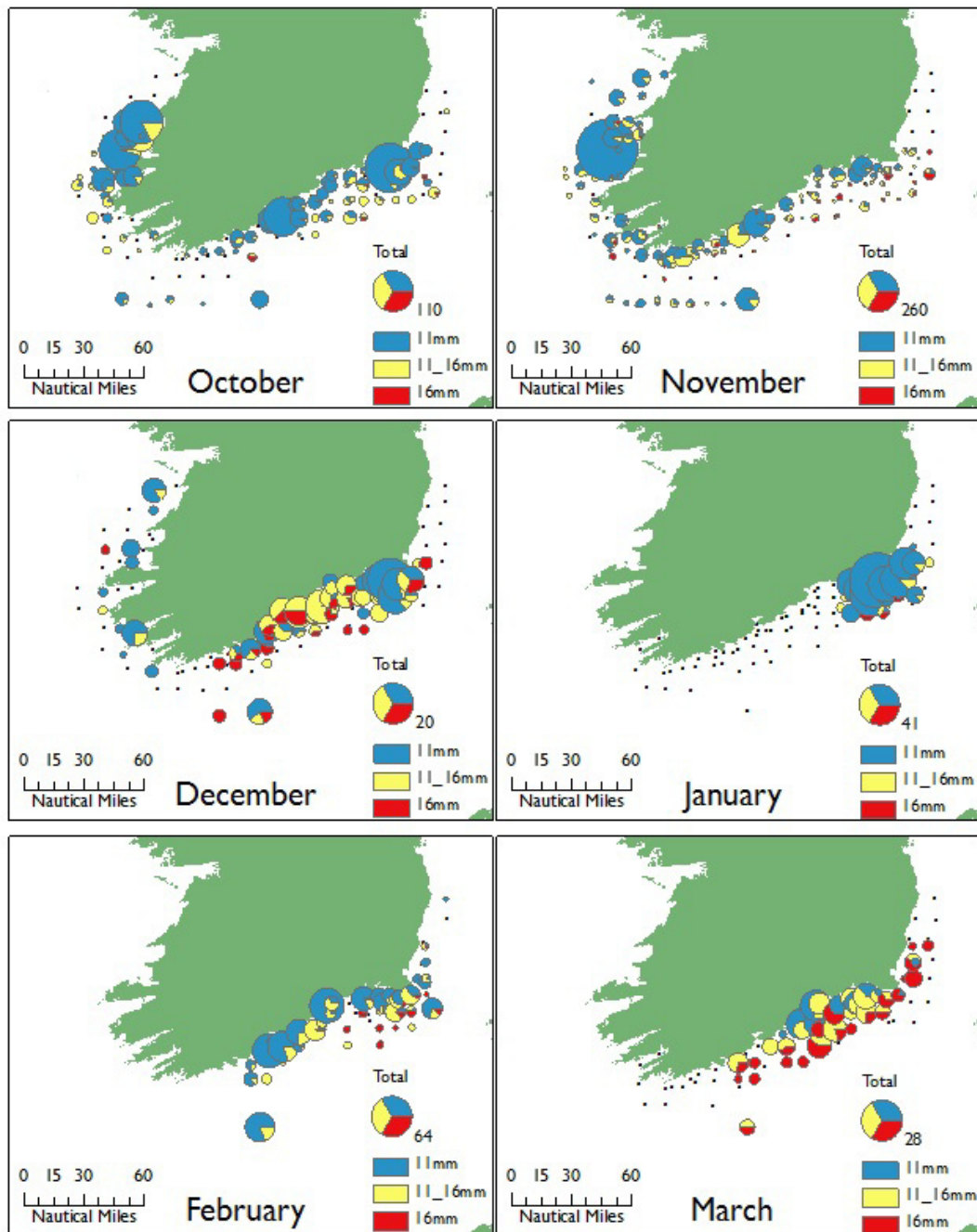
**Figure 2 Continued.** Herring beds and herring grounds (named only) within each main spawning area. The area (km<sup>2</sup>) of each spawning area and the number of beds and grounds within is indicated, along with available supervised seabed classification data collated by MeshAtlantic. These data have been translated to a EUNIS classification system following Davies *et al.* (2004).



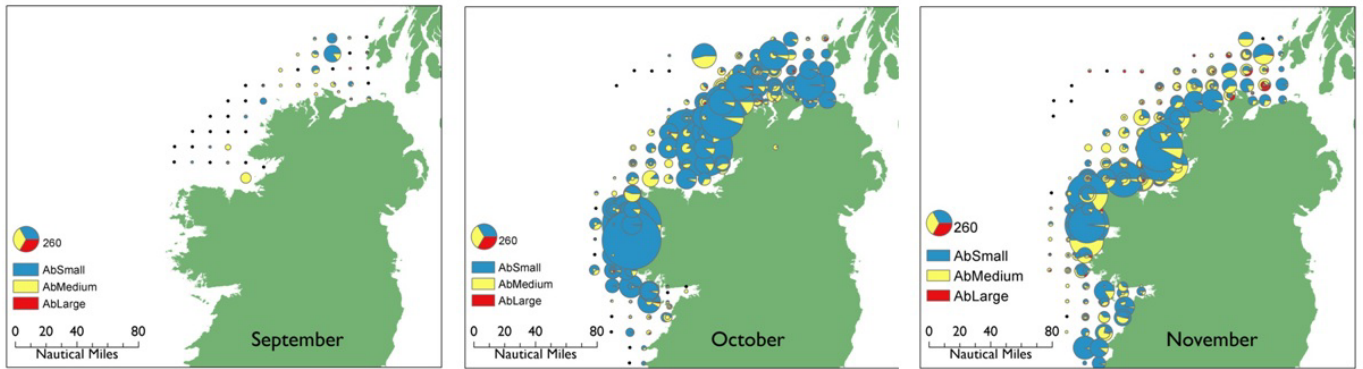
**Figure 3.** Herring spawning beds identified in the present study in conjunction with INFOMAR bottom type classification data (where available).



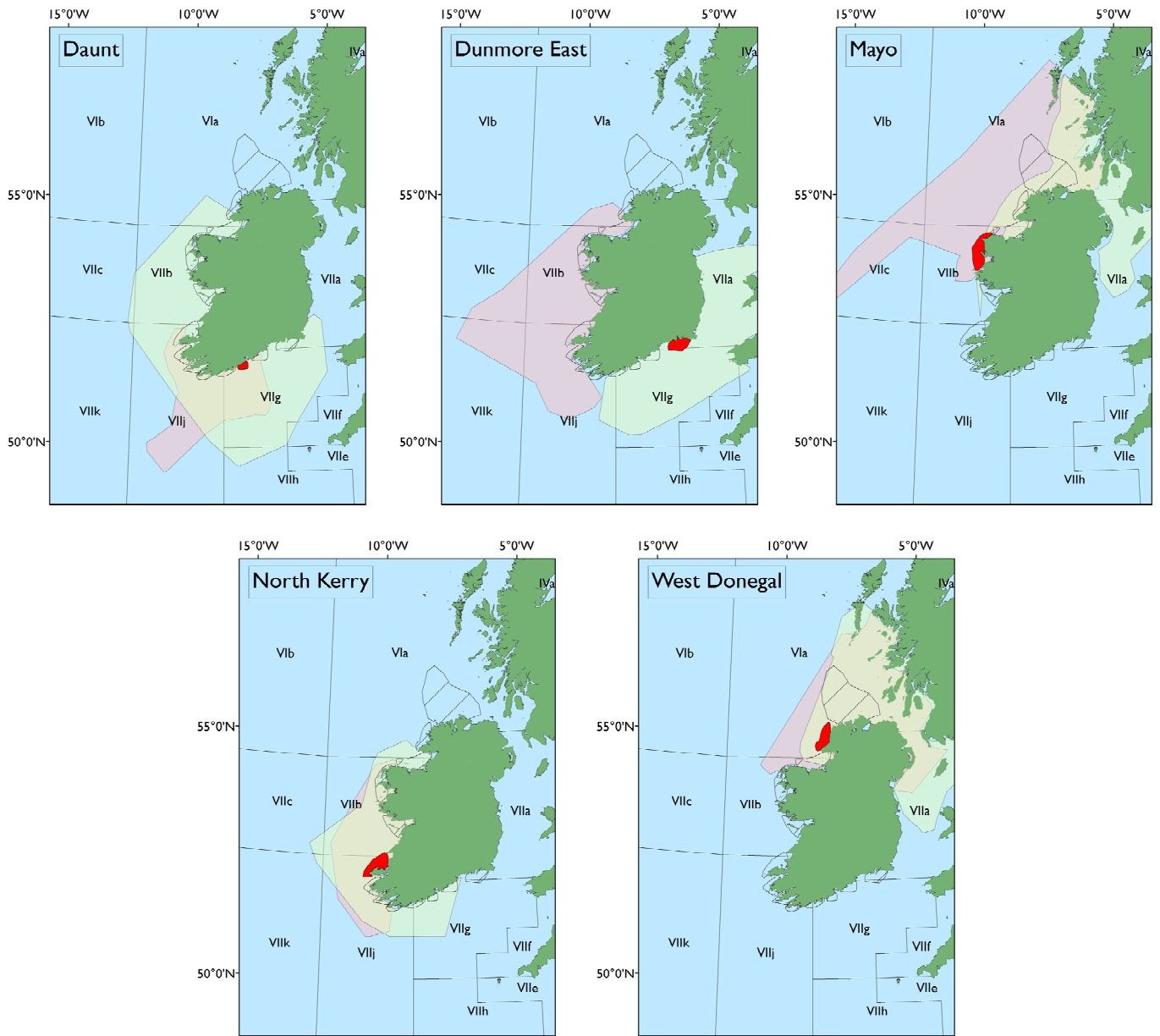
**Figure 4.** The timing of peak spawning activity at each individual herring spawning bed identified in this study, in both the Celtic Sea and the northwest coast, based on interview data.



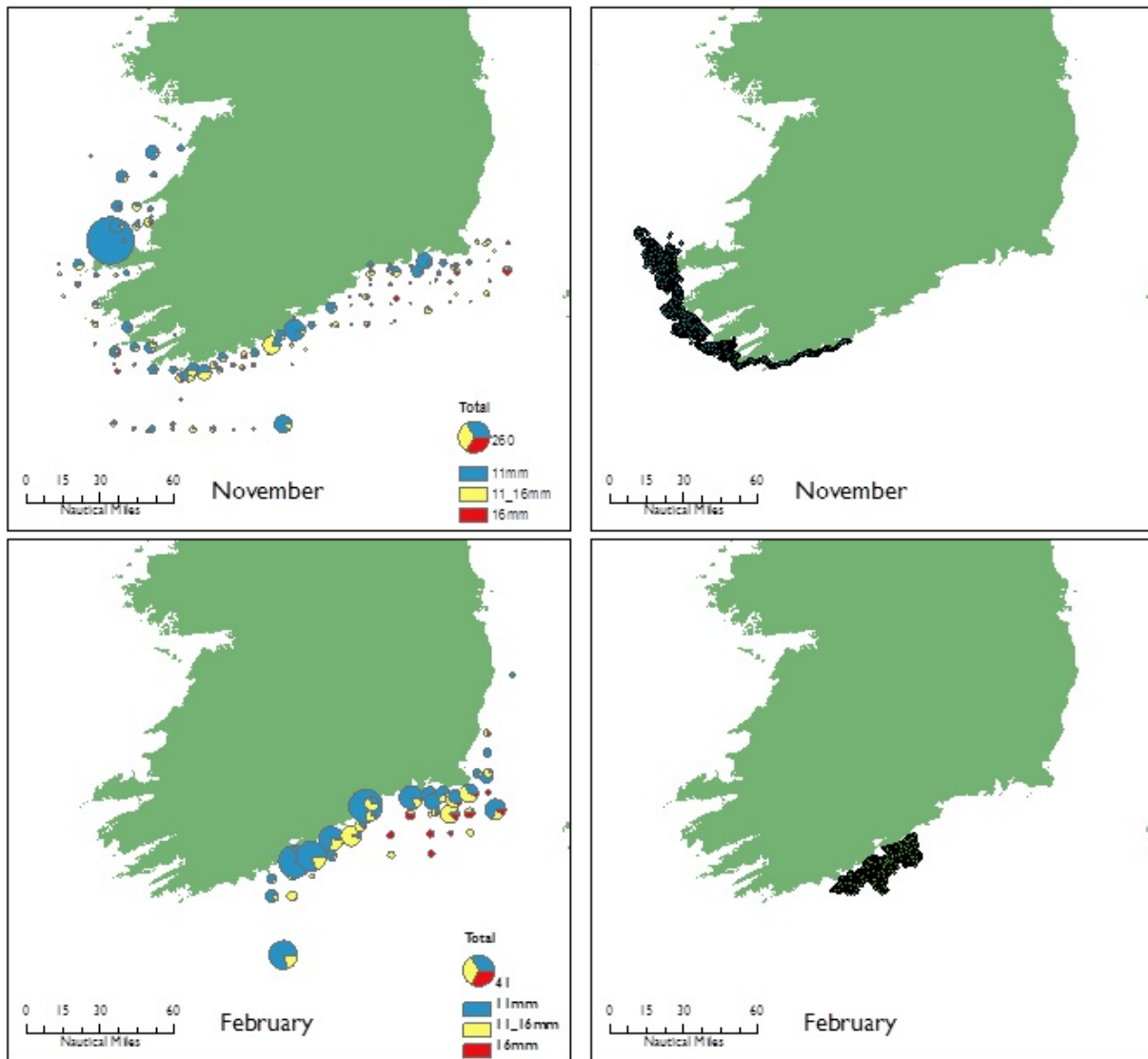
**Figure 5.** Monthly abundance and distribution of herring larvae size classes from previous larval surveys in the Celtic Sea from 1978-1985 and 1989-1990 (Grainger, unpublished data). The abundance (m<sup>-2</sup>) of herring larvae grouped into different size classes (<10mm, 10-16mm and >16mm), note different abundance scales. Black dots indicate survey effort with no recorded larvae.



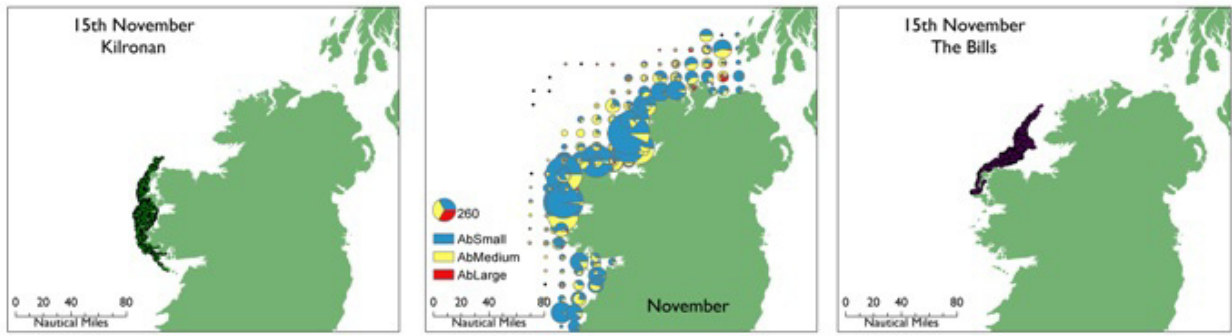
**Figure 5 continued.** Monthly abundance and distribution of herring larvae size classes from previous larval surveys in the Northwest from 1981-1988 (ICES Herring Larvae Database). The abundance (m<sup>-2</sup>) of herring larvae grouped into different size classes (Small <10mm, Medium 10-16mm and Large >16mm). Black dots indicate survey effort with no recorded larvae.



**Figure 6.** Predicted dispersal fields of herring larvae after four months from five spawning areas (highlighted red) for both Oct/Nov spawners (light green) and Jan/Feb spawners (pink) using the particle tracking model.



**Figure 7.** Distribution of herring larvae as predicted from the larval tracking model, and as observed from larval surveys (Grainger unpublished). Here the predicted dispersal of herring larvae after two weeks (released from the Daunt on 1<sup>st</sup> of November and 1<sup>st</sup> of February respectively) is compared with larval distribution for both months (averaged) as observed from larval surveys (1978-1985, 1989-1990).



**Figure 7 continued.** Distribution of herring larvae predicted by larval tracking model and as observed from larval surveys 1981-1988 (ICES Herring Larvae Database). Here the predicted dispersal of herring larvae after two weeks released from Kilronan (Galway Bay) and The Bills (Mayo) on the 1<sup>st</sup> of November (left and right respectively) and tracked for two weeks is compared with larval distribution for mid-November as observed from larval surveys (1978-1985, 1989-1990).

ISSN 1649-5055

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