Irish Fisheries Investigations No. 24 2012

The Status and Management of Oyster *(Ostrea edulis)* in Ireland

Oliver Tully

Sarah Clarke

Marine Institute
Foras na Mara

The Status and Management of Oyster (*Ostrea edulis*) in Ireland

2012

Oliver Tully and Sarah Clarke

The Marine Institute, Fisheries Ecosystems Advisory Services, Rinville, Oranmore,

Co. Galway

ISSN: 1649 0037

Further copies of this publication may be obtained from the Marine Institute, Rivnille, Oranmore, Co Galway, Ireland. Alternatively, a PDF version maybe downloaded from: www.marine.ie

Acknowledgments

Vera O'Donovan, Seamus Breathnach, Declan Nee and Owen Doyle of BIM participated in a number of surveys. Staff of Inland Fisheries Ireland and Francis O'Beirn (Marine Institute) assisted with the Lough Swilly surveys. We are grateful for the local knowledge and assistance provided by oyster fishermen and to the Oyster co-operatives for facilitating the work.

Funding

This project was part funded by the Marine Institute and by the European Union under the National Development Plan 2007-2013 through the Marine Environment Protection Measure.

Abstract

Fourteen oyster surveys were completed during 2010-2012 in 6 bays on the west coast of Ireland prior to and following annual late autumn fisheries. Vessel based surveys using locally designed dredges were undertaken using in Tralee Bay, Galway Bay, Kilkieran Bay, Clew Bay, Blacksod Bay and L. Swilly. Survey extent was defined by local knowledge of the distribution of beds in each bay and from previous survey reports. The extent of oyster beds, oyster densities, biomass, size composition and growth and mortality rates are reported. The governance and management of oyster fisheries in Ireland is described and conservation requirements for oyster habitat are discussed with reference to the EU Habitats Directive.

Survey extents varied from 0.9-13km^2. Population densities of oyster were generally <0.5 oysters m^{-2} but higher densities of up to 50 oysters m^{-2} occurred in areas of inner Tralee Bay. In other sites, densities did not exceed 5 oysters m^{-2}.

The majority of national oyster biomass occurred in inner Tralee Bay where biomass varied from 980-1330 tonnes in the 2010-12 surveys. Biomass in outer Tralee Bay and L. Swilly was approximately 100 and 124 tonnes, respectively. Biomass estimates in inner Galway Bay, Kilkieran Bay, Clew Bay and Blacksod Bay were all less than 50 tonnes.

vonBertalanffy growth parameters, k and t_o, were 0.21year^{-1} and 0.23years respectively. These parameters were estimated from shell height frequency data and by fixing L_{inf} at 120mm, based on the maximum size of oysters recovered during surveys. Total mortality rates (Z) were estimated from the linear portion of length converted catch curves using these derived growth parameters. Z estimates, in pre and post fishery surveys, averaged 1.07 and 1.30 respectively in 2010 and 0.94 and 1.55 respectively in 2011. Fishing mortality rate (F), derived from the difference in Z estimates in pre and post fishery surveys in inner Tralee Bay, was 0.9 representing an annual removal of 60% of oysters recruited to the fishery. Increase in biomass of a single cohort, simulated using derived growth rate parameters, the size weight relationship and different rates of natural mortality (M) suggests that maximum biomass develops prior to the minimum landing size of 76mm if M>0.4. Improved, site specific, estimates of growth and mortality rates and size at maturity data are needed to provide fisheries management advice for native oysters.

Pacific oyster (*Crassostrea gigas*) was abundant and widespread, in what was previously *Ostrea* habitat, in L. Swilly. In some of these areas, Pacific oyster was the only oyster species present. In other areas both species co-existed although they were spatially segregated to a degree in relation to shore level.

Contents

List of Tables and Illustrations

1 Introduction

Although commercial fisheries for oyster continue in many oyster beds in Ireland, data on the distributional extent and status of native oyster have not been reported in recent years (Barry 1981, Whilde 1973). Oyster stocks are, however, known to have declined significantly in Ireland compared to the historic highs of the 19th century. The species is listed by OSPAR as threatened or declining and a number of pressures from coastal development, disease and alien species continue in many areas (OSPAR 2009). All commercially fished oyster beds in Ireland occur in Special Areas of Conservation (SAC) designated under the Habitats Directive (Council Directive 92/43/EC). Oysters are potentially keystone habitat (reef) forming species or important characterising species in these areas and the maintenance of favourable conservation status (FCS) of oyster habitat is a requirement under conservation objectives now being defined for these habitats (NPWS 2011a,b). Sustainable exploitation consistent with the maintenance of FCS should, therefore, be a primary management objective for these fisheries. Strategies to achieve this objective need to be founded on basic information on extent, biomass, size and age composition and recruitment to native oyster beds. These attributes are reported here for 6 oyster producing areas and 14 surveys completed during the period 2010-2012. In addition, historic and current production of oyster in Ireland is briefly reviewed, strategies for the management of oyster fisheries in SACs are discussed and the governance and management of oyster fisheries in Ireland today is described.

1.1 Historic production

The history of oyster fishing in Ireland is documented back to the 1500s (Went 1962). Although the records on national production are incomplete, the peak in output appears to have been in the mid and late 19th century. This was due significantly to the offshore, but short-lived, fishery in the Irish Sea and also the Galway fishery which was important up to the early 20th century. Overall, the long term trends in national production, from descriptions given in Went (1962), is of fluctuation with local extinctions or severe declines and various attempts at restoration. By 1870, half of the Irish production originated from Arklow and Wexford and, in addition, substantial quantities of oyster were taken directly from this area by English boats. In 1871, the Arklow and Galway beds were described as being the main production areas. Production from these beds peaked at 34-38million oysters into Ireland in 1863 and 1864. The reported statistics then demonstrate a precipitous decline in production from these areas over the following years up to 1888 (Figure 1).

Important oyster fisheries have existed at approximately 50 locations around the coast at one time or another (Went 1962). In 1903, 24 public oyster beds were listed in Ireland with Tralee, Carlingford, Galway Bay, Cork Hbr, St. Georges Channel and Lough Foyle being the most important. The "once prolific public beds" in Cork, Shannon, Clew Bay and Blacksod Bays were yielding very little by the early 20th century. In addition, there were 8 chartered beds (areas where rights were claimed by virtue of a lease from the Crown and usually associated with grants of land) at Sutton, Clontarf, Cork Hbr, Sneem, Kilmacallogue, Kilkieran, Cashel, Beirtreach Bui and Malahide. The only self-recruiting stock in this list was in Kilkieran Bay. The other areas were used for relaying, storing and fattening of native and American oysters (*Crassostrea virginica*). In addition, there were 62 oyster beds covered by licences under the Irish Fisheries Acts. Important licenced areas in this category were at Clifden Bay, Ardfry, Barrow, Burren, Pollagh (Kinvara) and Sligo Bay. There were also a number of unlicenced layings. Oyster production involved a range of activities from purely fishing of wild stocks to establishing grounds and 'put and take' operations with native, American and Portugese oysters (*Crassostrea angulata*). Some areas, where growth rates may have been low, were used as sources of seed which were taken and re-laid into 'fattening areas' prior to sale.

Historically, attempts to manage stocks were effected through a range of licencing regimes from open public access to private licences of various forms. Causes of the dramatic decline in the important stocks are clear in some cases. In Arklow, heavy fishing pressure over a number of years decimated the offshore beds. Although these beds were extensive they were probably not highly productive and larval retention and settlement in these areas may have been sporadic. In coastal bays and estuaries, overfishing or unregulated fishing played a strong role in decline of stocks (Smyth *et al*. 2009). Poor compliance with bye-laws was also implicated as the Fishery Authorities were debarred from direct enforcement of them (Holt and Hillas 1905). However, it is difficult to separate the effects of fishing from environmental effects on recruitment and productivity over longer periods of time. Cold winters of the 1940s and early 1960s probably contributed to mortality of spawning stock in shallow water areas (Orton, 1940; Kennedy and Roberts 1999). Habitat loss (Laing 2006) and more recently, *Bonamiosis* infection, first detected in Ireland in 1987 (McArdle 1991), has had a significant deleterious effect on stocks. Other species of parasite such as *Marteilia refringens* have also been responsible for decline of *O. edulis* in France and Spain (Anon 2005). This accumulation of pressures may have been incompatible with maintenance of populations in which reproduction and recruitment may have been irregular and insufficient to counter high mortality rates.

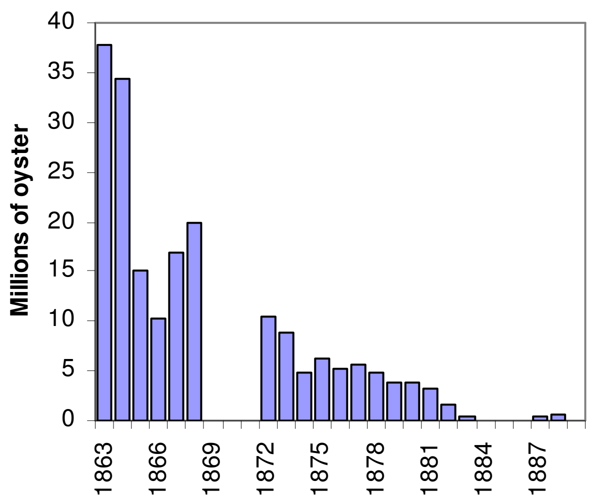

Figure 1. Landings of oyster into Ireland from the Irish Sea and Galway Bay between 1863 and 1889 derived from data reported in Went (1962).

1.2 Current production

Today, the principal fisheries for native oysters in Ireland are in Tralee Bay and to much lesser extents in inner Galway Bay, Lough Foyle, Lough Swilly, Kilkieran Bay and, infrequently, in Blacksod Bay and Clew Bay. Annual national production fluctuates between 100-300tonnes depending on the decisions of oyster managers to open beds, annual total allowable catches (TACs) for beds that are opened and trends in biomass (Table 1).

Table 1. Landings (tonnes) of oyster into Irish ports annually between 2004-2011. Source: Sea Fisheries Protection Authority and Oyster co-operatives. Records may be incomplete.

County	Port	2004	2005	2006	2007	2008	2009	2010	2011
Cork	Kinsale			5					
Donegal	Buncrana	170	55	53	51	43	20	12	4
Donegal	Greencastle							45	
Donegal	Moville	86		45	96	20	42	79	
Galway	Carna	20	28						
Galway	Kilkieran							18	
Galway	Clarinbridge	20		25		25	25	15	15
Kerry	Cromane				4				
Kerry	Inner Tralee	240			140		240	180	100
Mayo	Achill	7	5	6					
Mayo	Belmullet			90					?
Mayo	Westport		6	9					
Total		**543**	**94**	**233**	**291**	**88**	**327**	**349**	**115**

1.3 Conservation of *O. edulis*

O. edulis has declined significantly throughout Europe since the 1970s. In the UK Biodiversity Action Plan (BAP), it is categorised as having declined by over 50% in 25 years (UKBAP 1999). The species was included on the OSPAR list of threatened and/or declining species and habitats in 2003 (OSPAR 2009). Although not listed as an Annex species in the Habitats Directive, native oyster beds potentially falls within the definition of Habitat 1170 (reef) as defined in the Directive and oyster is potentially a characterising and/or key structural species in sedimentary habitats in estuaries (Habitat 1130) or large shallow inlets and bays (Habitat 1140). *O. edulis* is recorded as a structural reef forming species in shallow (7-20m) waters in exposed and semi-exposed coasts of the Black Sea although the presence of serpulid polychaetes seem to be important in providing cementing material for reef formation (Todorova *et al*. 2009). In Ireland, at least in the 20th century and in shallow water areas, topographic biogenic reefs formed by native oyster have not been documented. In all these cases, however, the beds have been disturbed by fishing activity for decades or centuries. The structure and function of offshore oyster beds in the Irish Sea and similar beds in the southern North Sea and English Channel, all of which are now extinct, is not well documented. However, given the production of oysters from these offshore beds, in the 19th century, it is likely that oysters formed continuous cover over extensive area of seabed. The extent to which these oyster beds constituted topographic biogenic reef is unknown. Presumably, however, they supported a high biodiversity as to mussel reefs today for instance (Coleman and Williams 2002).

In Irish inshore waters practically all significant oyster populations occur or have occurred in estuarine areas where there is significant freshwater inflow. The capacity of oyster to form reefs in these environments depends on the 'shell budget'. That is to say, the rate at which shell accretes onto a reef should be greater than the rate at which it is lost if the reef is to grow. Estuarine environments are unpredictable and potentially stressful to native oyster with respect to salinity change, sediment deposition rates, physical disturbance and temperature extremes. These areas are variously exposed to wind induced wave action which can turn-over shell and sediment resulting in mortality of juvenile oysters in particular. Spawning, larval settlement and recruitment fail regularly and the populations are maintained by periodic re-cruitment events. Adult oyster shell is also not well preserved in these estuarine environments (Powell *et al*. 2006). Today, oyster beds are exposed to a number of additional pressures that were absent prior to major human exploitation, which extends back to the 1500-1700s in Ire-land. These include fishing, competition from introduced species such as *Crassostrea gigas* (Pacific oyster) and infection with *Bonamia* in particular. Nevertheless, oyster beds in estua-rine waters provide, in some cases at least, a shell rich habitat in mixed sediments. In these areas, if spawning potential is sufficiently high, if environmental conditions favour frequent reproduction and if natural and fishery induced physical disturbance and mortality is low, the 'shelliness' of such habitats may increase and dead shell may accumulate forming topog-raphic relief. As in the Black Sea example, the presence of other accreting organisms such as serpulid worms could potentially lead to development of bio-genic oyster reefs. These condi-tions do not, however, coalesce in any oyster producing area in Ireland at this time, nor have they probably done so for at least 200 years, in the main producing areas.

1.4 Governance and licencing of oyster fisheries in Ireland

The governance and licencing of native oyster fisheries in Ireland varies depending on loca-tion. Oyster stocks and their fisheries are in some cases managed under Aquaculture li-cences issued by the Department of Agriculture, Food and Marine (DAFM) (Table 2). These licences are renewed every 10 years and part of the renewal condition is that a production and management plan for the relevant oyster bed be developed. In other areas, the manage-ment of oysters has been devolved to Co-operatives or Societies in Fishery Orders (FOs) un-der the Fisheries Act, 1959. These orders give, essentially, permanent rights of access to a co-op or group to produce oysters within the order area although the Minister may revoke or-ders in certain circumstances. These FOs are administered by the Department of Communi-cations, Energy and Natural Resources (DCENR). Oysters are also fished in areas not sub-ject to FOs or Aquaculture licence but as public fisheries and include the oyster beds in L. Swilly and the 'public' bed in Galway Bay. The FO for the St. Georges bed in Galway Bay is currently owned by the state agency, Bord Iascaigh Mhara (BIM), and some beds also remain in private hands the title being linked to land title.

In all cases, operators using a dredge to fish for oysters require a dredge licence from Inland Fisheries Ireland (IFI). A licence fee applies. Vessels operating in these fisheries must be listed on the Register of Sea Fishing Vessels administered by DAFM. Where they operate in public beds, the vessels should have either bivalve or polyvalent 'tonnage' attached. Vessels operating in Aquaculture or FO areas do not require tonnage and can be registered in the Aquaculture Segment of the Irish fishing fleet. Vessel operating in Aquaculture and FO areas must also have a permit from the local Co-op. A permit fee usually applies.

Whether in Aquaculture licenced areas, FO areas or in public beds the various oyster co-operatives or societies manage exploitation of the beds to varying extent. A minimum landing size of 76-78mm applies universally. Some co-ops impose a TAC, the opening and closing dates of the season and, in some cases, the total number of permits they issue. The TAC or other measures are usually not based on scientific advice although this has varied over the past 40 years depending on where and how often such data and advice is available.

Table 2. Licencing framework for the principal native oyster fisheries in Ireland

Site	**SAC**	**Licencing**					**Other bivalve species fished or produced**
		Aqua-culture	**Fish-ery Order**	**Public fishery**	**State owned**	**Private**	
Galway Bay (Clarinbridge)	Yes	No	Yes	No	No	No	Pacific oyster
Galway Bay (Public bed)	Yes	No	No	Yes	No	No	
Galway Bay (St. Georges Bed)	Yes	No	Yes	No	Yes (BIM)	No	
Galway Bay (Ballynacourty)	Yes	No	No	No	No	Yes	
Kilkieran Bay	Yes	Yes	No	No	No	No	Scallops
Tralee Bay	Yes	No	Yes	No	No	No	
Blacksod Bay	Yes	Yes	No	No	No	No	
Lough Swilly	Yes	No	No	Yes	No	No	Mussels, Pacific oyster
Clew Bay	Yes	No	Yes	No	No	No	Pacific oyster, Scallop

2 Methods

2.1 Surveys of stocks 2010-2012

All the main oyster beds in Ireland that have been producing oysters in recent years were surveyed between 2010 and 2012 (Figure 2, Table 3). Fishing for native oysters, in Ireland, usually commences during late autumn or in December and the fisheries are usually closed again in early Spring. Surveys were generally undertaken either before or after the seasonal fishery and in some sites surveys were completed both before and after the fishery. A total of 14 surveys in 6 Bays were completed between Sept 2010 and Feb 2012. In Tralee Bay there are discrete and separate beds in the inner and outer areas of the Bay. These are reported separately.

Local oyster fishing vessels, using local dredge designs, were used in all surveys. Dredges were generally 1.2m wide with either teeth or blade and with soft or rigid frame bags. Local rather than standardised dredges were used so that the operating skills of the skipper were not compromised and catch rates were reflective of local fishery conditions. Dredge efficiencies was estimated for the dredges used in Kilkieran Bay and Clew Bay. Here the start and end of a number of dredge tows were marked by surface marker buoys and divers surveyed the tracks after the dredge had been towed between the buoys. All oysters found in the dredge track were retained and counted by the divers and compared to the catch of the dredge. The divers were presumed to be 100% efficient in finding oysters in one pass over the dredge track. A total of 24 dredge tracks were re-counted by divers in Kilkieran and Clew Bays.

Surveys were planned by outlining the extent of the oyster bed on admiralty charts either from local knowledge or reported extents of the beds from previous surveys. Grids were established over these areas, at various resolutions depending on the size of the bed and survey time available, and a dredge tow station was allocated to the centre point of each grid cell. The knowledge of the local skipper was, however, taken into account during the surveys and stations were re-allocated randomly to areas indicated as 'oyster bed' by the skipper. In order to define the extent of the beds, tows were taken towards the edges of the beds as indicated by patterns of zero catches. The dredge was towed for approximately 50m at each station. Distance towed was measured using a Trimble® Nomad GPS unit which recorded GPS position every 5m and at start and end of the tow. Dredge track GPS position and oyster catches were, subsequently, downloaded and incorporated into ArcGIS 9.3®. Survey extent was redefined by creating a new 'mask' polygon incorporating all positive survey stations and excluding areas which had consistent zero catches. This 'mask' constrained the extent over which oyster densities were subsequently interpolated. Oyster numbers per tow were converted to oyster densities and raised to account for dredge inefficiency. Oyster densities were then interpolated (ArcGIS Spatial Analyst) using the Inverse Distance Weighting (IDW) algorithm. This interpolation method averages the values of sample data points in the vicinity of each cell in the raster surface being estimated. A power value in the interpolation can be used to control the weighting of points based on geographic distance from the point being calculated. Specifying low power, such as 2 in the present case, gives more influence to distant points and a smoother surface. The search radius was varied so that at least 6 sampled points were used in calculating the interpolated cell. Neighbourhood areas used to calculate interpolated points were, therefore, variable depending on the sampling effort close to the cell being interpolated.

Density contours were drawn at intervals to reflect the range in oyster density over the survey grid and the geographic area within each contour was calculated. Mean biomass of oysters (B_{mo}) and its confidence limits per square meter within the contour was calculated as

$$B_{mo} = (D \pm d) * (W \pm w) = D * W \pm ((D * W) * \sqrt{d^2 / D^2 + w^2 / W^2})$$

where, D is average density of oysters at stations within the contour, d is the confidence limits for the average density, W and *w* is the mean weight and confidence limits, respectively, of oysters at stations within the contour, calculated from the size weight relationship.

Total biomass within each contour (B_c) was calculated from the product of the mean biomass within the contours and the geographic area encompassed by the contour given by the equation,

$$B_c = B_{mo} * A_c \pm CL_{Bmo} * A_c$$

where, B_{mo} is the biomass per square meter within a contour area, A_c is the area encompassed by the contour, CL_{Bmo} is the confidence limit for the biomass per square meter within the contour area as calculated above.

Finally, the total biomass (B_t) and its CL was obtained by summing the biomass estimates for all contours

$$B_t = \sum_{c=1}^{n} (B_c \pm CL_{Bc})$$

Table 3. List and timing of oyster surveys at 7 locations in relation to fisheries in 2010-2012.

Site	2010/2011		2011/2012	
	Pre-fishery	Post-fishery	Pre-fishery	Post-fishery
Inner Tralee Bay	Sep 2010	Jan 2011	Sep 2011	Feb 2012
Outer Tralee Bay	Sep 2010		Feb 2012	
Kilkieran Bay	Oct 2010	Jan 2011		
Blacksod Bay		Jan 2011		
Clew Bay	Oct 2010			
Galway Bay		Apr 2011		Feb 2012
Lough Swilly		Mar 2011	Nov 2011	

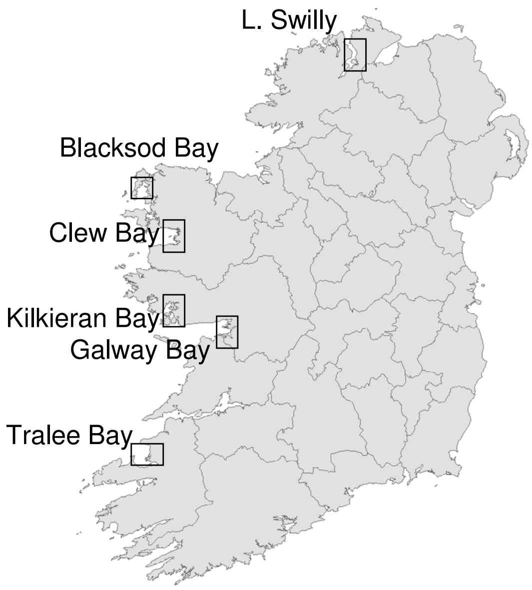

Figure 2. Areas where oyster surveys were completed in 2010-2012

2.2 Estimation of growth and mortality

Size at age data for oysters aged 0-3yrs were extracted from length frequency distributions from the survey, from Galway Bay data obtained in July 2011 (not shown) and from data presented in Barry (1981) for Kilkieran Bay. Normal distributions, assumed to represent age classes, were fitted to the length frequency distribution mixtures using maximum likelihood estimation and the solver routine in Excel. A birth date of end of June was assigned to scale the age data and mean size at presumed age was estimated. The vonBertalanffy growth function (King 1995) was fitted to the data using maximum likelihood methods and the solver routine in Excel and a fixed asymptotic size ($L_\propto$) of 120mm, which corresponded, approximately, to the largest oysters observed during surveys. A fixed $L_\propto$ was used because of the limited age range for which size was estimated and to enable convergence during the fitting process. The von-Bertalanffy growth model is defined as

$$L_t = L_\propto \left(1 - e^{-k(t-t_0)}\right)$$

where L_t is size at time t, $L_\propto$ is asymptotic length at which growth is zero, k is the rate at which size approaches $L_\propto$ and t_0 is the age at zero size.

The rate of total mortality (Z) was estimated from the right hand portion of the length distributions after converting numbers at length to numbers at age using the estimated growth parameters which included seasonality in growth. Accounting for seasonal growth is important in eliminating bias in Z estimates caused by seasonal growth patterns (Pauly 1990). A linear regression of Ln(Number) on relative age was fitted to the descending and linear portion of the resulting length converted catch curves. The slope of the regression, representing the decline in numbers with age, provides an estimate of Z. The method assumes steady state conditions or, essentially, that recruitment is constant. Although this is clearly not valid for oysters, it is useful to compare Z estimates across surveys. Generally, Z estimates were higher from surveys completed after a recent fishery had occurred compared to surveys where a fishery had not occurred for 9-12months. A fishing mortality signal, for oysters over 76mm, was, therefore, evident in the size distributions and in the Z estimates.

The relationship between shell size and weight was described by a power function as

$$W = a * S^b$$

where W is weight, S is shell size, a is a scaling factor and b, the exponent, describes the rate of increase in weight with increase in shell size.

2.3 Evolution of biomass

Following settlement, the biomass of spat increases over time as a function of growth rate and total mortality. Ideally, harvesting would occur at a time and at a shell size at which total biomass of the cohort had reached a maximum or at the point in time where effects of mortality and growth were balanced. Harvest strategy would also need to consider size at maturity, preservation of spawning biomass and the market preference. This evolution of biomass can be simulated by exposing a given recruitment to mortality and growth. Mortality effects on oysters <76mm are due to natural causes only (M) (ignoring mortality that may be caused by contact with the dredge) while mortality on oysters >76mm is a function of both natural mortality and landings or fishing mortality (F). The total mortality (Z) results from the additive effect of M and F. The size or age at which biomass of the cohort is at a maximum depends on the relative rates of mortality and growth. In this study, the evolution of biomass of a single theoretical cohort, as a function of age and shell size, was simulated for values of M ranging from 0.2-1.0, given that M is unknown, and at zero F. These rates were used to drive an exponential decay of the cohort and, thereby, to provide numbers of oysters in each size and age class over time under each M scenario in steps of 0.2. Secondly, an F of 0.9 was applied to survivors that had reached 76mm. This value of F was obtained from the average difference in Z between pre-fishery and post-fishery surveys and was thought to represent the real rate of F operating on legal sized oysters in commercially fished stocks in Ireland. Weight at size of the survivors was estimated from the size weight relationship and biomass of the survivors from the sum of the individual weights. This analysis is not a standard yield per recruit or biomass per recruit assessment but simply describes the evolution of biomass of a single cohort (settlement) under different conditions of mortality and growth rate.

3 Results

3.1 Dredge efficiency

Dredge efficiency estimates were highly variable ranging from 0-100%. On average, taking all dredge tracks in which at least 1 oyster was recovered, dredge efficiency was 32±32%. Previous estimates by Brown *et al.* (2006) indicated an efficiency of 36%. An efficiency of 35% was used here to raise the survey counts to densities of oysters except in inner Tralee where an efficiency of 17% was used. This figure was based on an exploitation rate estimate of 77% due to the fishery in December 2010 which resulted in landings of 170 tonnes of oysters from inner Tralee Bay and suggested a total biomass (at 100% exploitation) of 220 tonnes. The survey estimate, uncorrected for dredge efficiency was 38 tonnes. The survey estimate divided by the total biomass estimate (38/220) is an indirect measure of dredge efficiency of 17%.

3.2 Distribution, extent and population density

Taking all surveys together, oyster density ranged from 0 to 50m^{-2}. However, density was usually less than 1m^{-2}. On average, 27% of stations surveyed had no oysters and 48% had oyster density between 0-0.5m^{-2} (Figure 3). The proportion of stations with no oysters may be overestimated because zero counts could not be corrected for dredge inefficiency.

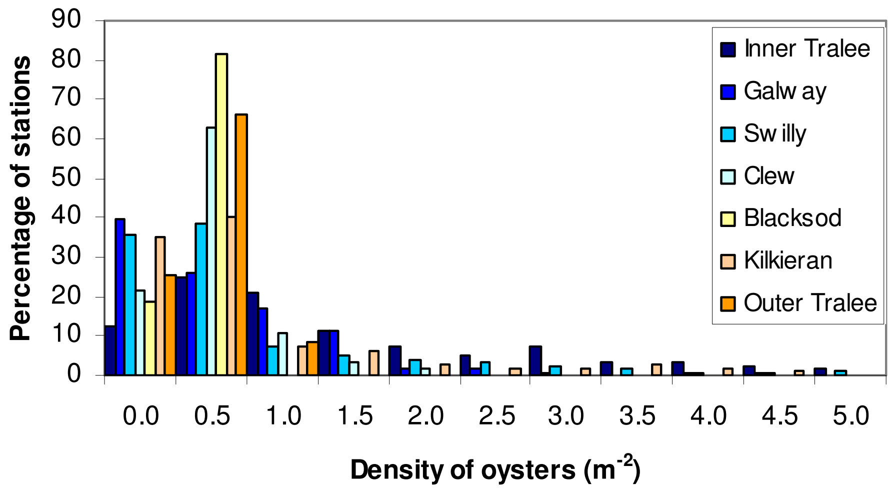

Figure 3. Distribution of oyster density (0-5m^{-2} range only) in 7 oyster beds between 2010 and 2012. Raw Counts have been raised by a factor of 2.85 as a correction for 35% dredge efficiency except in Inner Tralee Bay where dredge efficiency was estimated to be 17% and a factor of 5.9 was used

The surveyed areas (Table 4, Figure 4 & Figure 5) may underestimate the actual extent of oyster distribution as systematic zero counts towards the edges of the surveyed areas were not detected in all surveys. Nevertheless, the surveys, which specifically used local knowledge of experienced oyster fishermen, probably incorporated all significant oyster beds currently present in these sites.

In inner Tralee Bay, the full extent was identified at approximately 4km^2. Highest densities and the majority of the biomass occurred in estuarine areas east of Fenit. This pattern was consistent across all 4 surveys completed in 2010-2012 (Figure 4). Densities ranged from 0-50m^{-2}.

In outer Tralee Bay, the full extent of all beds was not completely determined. The 2012 survey was more comprehensive (Figure 4) and identified 2 separate areas, one in the west of Tralee Bay and a second to the south east of this area. The 2010 survey (not shown) identified a third area between and overlapping the beds surveyed in 2012. The full extent of oyster beds in the outer bay may be 4-5km^2. The beds are not continuous, however, and are interspersed with patches of rock and seagrass. Densities ranged from 0-5m^{-2}.

In Galway Bay, the 2011 survey (2.46km^2) overestimated the current extent of oyster beds as zero counts were recorded in many areas. This survey extended to the south of Eddy Is. and into Kinvara Bay. The second survey in 2012, covering 1.17km^2, reflects the distribution of the majority of the current biomass (and fishery) which occurs in the public oyster bed north east of Eddy Is. and west of the FO area in the Clarin River estuary (Figure 4). Densities ranged from 0-2.5m^{-2}. Pacific oyster are cultured in the FO area but were not present in the main *O. edulis* beds.

In Blacksod Bay, the survey in autumn 2011 covered an area of 2.39km^2 north of Claggan point immediately south of Belmullet. A separate smaller bed within this area, commercially fished in 2011, was not surveyed. Densities ranged from 0-1m^{-2} in the surveyed area.

In Lough Swilly, the limited survey (1.55km^2) in March 2011 underestimated the extent of oyster beds in the area. The area covered by the second survey (13.07 km^2) in November 2011 was an overestimate of extent as a lot of zero counts occurred in sub-tidal areas of Delap Bay and in the Ballymoney Flats south west of Inch Is. Oysters were common in intertidal areas of Delap Bay, on Inch flats north of Inch Is. and in intertidal and shallow sub-tidal areas south west of Ballygreen Pt. and southwest of Ballybegley Pt. Densities ranged from 0-3.8m^{-2} in the surveyed area. Pacific oyster also occurred in all of these areas as described below.

The distribution and extent of oyster beds in Kilkieran Bay was identified from two spatially non-overlapping surveys completed in the autumn of 2010 and spring of 2011. The surveys covered a total area of 1.73km^2. Oysters were not recovered from all areas and densities were generally low ranging from 0-2.5m^{-2}.

Identifying the extent of oyster beds in Clew Bay was difficult because of the complex landscape, very low densities and patchiness in the distribution of oyster in the area. The survey extent of 0.93 km^2 probably underestimates the distribution of oyster in inner Clew Bay. Nevertheless, the areas were targeted using the extensive local knowledge of the skipper of the survey vessel and as such the survey probably identifies the locations if not the full extent of the main oyster producing areas. Densities were low ranging from 0-1m^{-2}.

Table 4. Area (km^2) surveyed for oyster in 7 sites in 2010-2012.

Site	2010/2011		2011/2012	
	Pre-fishery	Post-fishery	Pre-fishery	Post-fishery
Inner Tralee Bay	4.26	Not estimated	3.57	3.80
Outer Tralee Bay	3.63		3.72	
Kilkieran Bay	1.06	0.67		
Blacksod Bay		2.39		
Clew Bay	0.93			
Galway Bay		2.46		1.17
Lough Swilly		1.55	13.07	

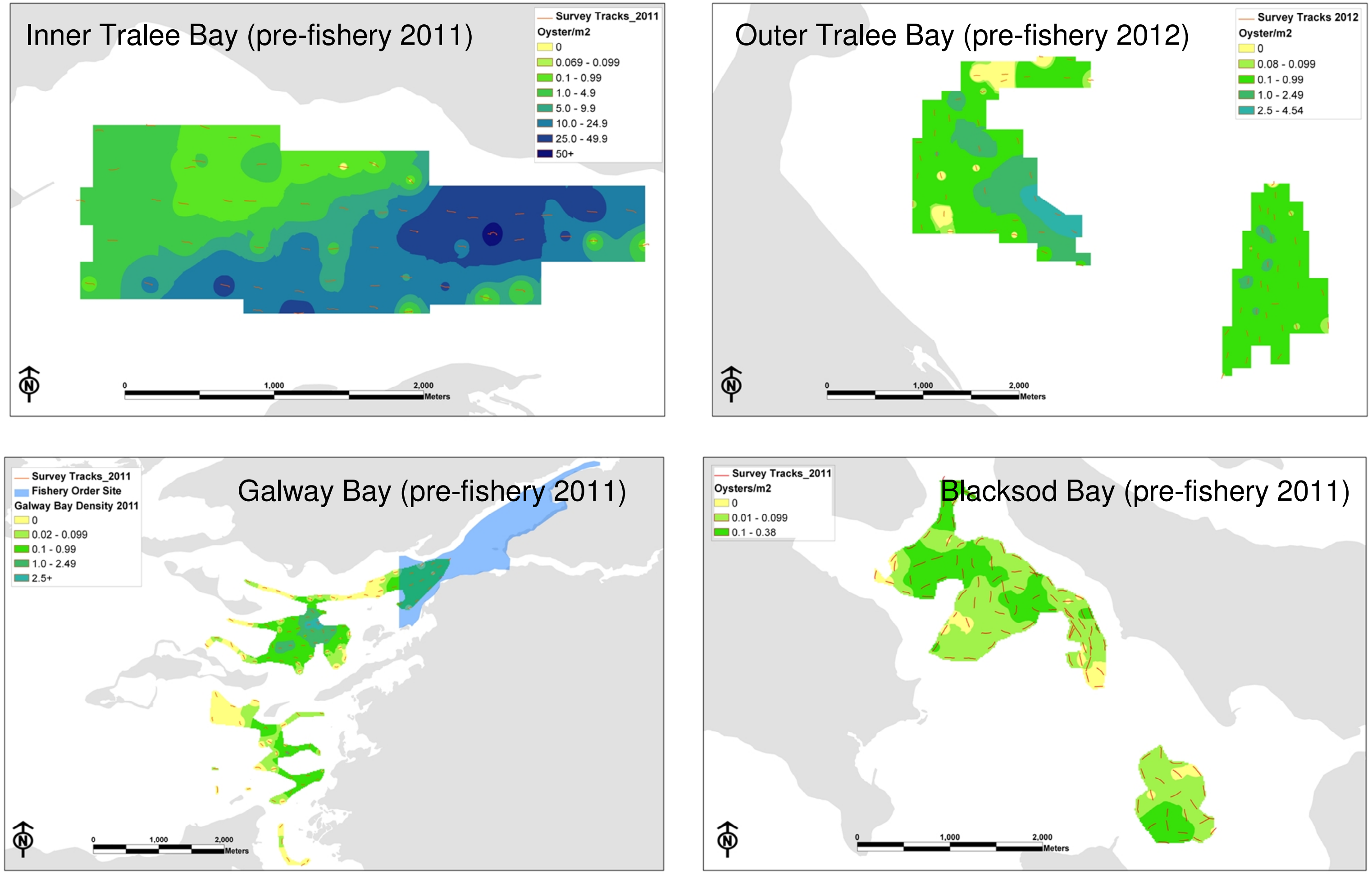

Figure 4. Distribution and density of native oysters in 4 sites surveyed between 2010 and 2012. Interpolation of densities is restricted to areas where there is sufficient survey information. The full extent of all oyster beds in outer Tralee Bay was not determined by the 2012 survey.

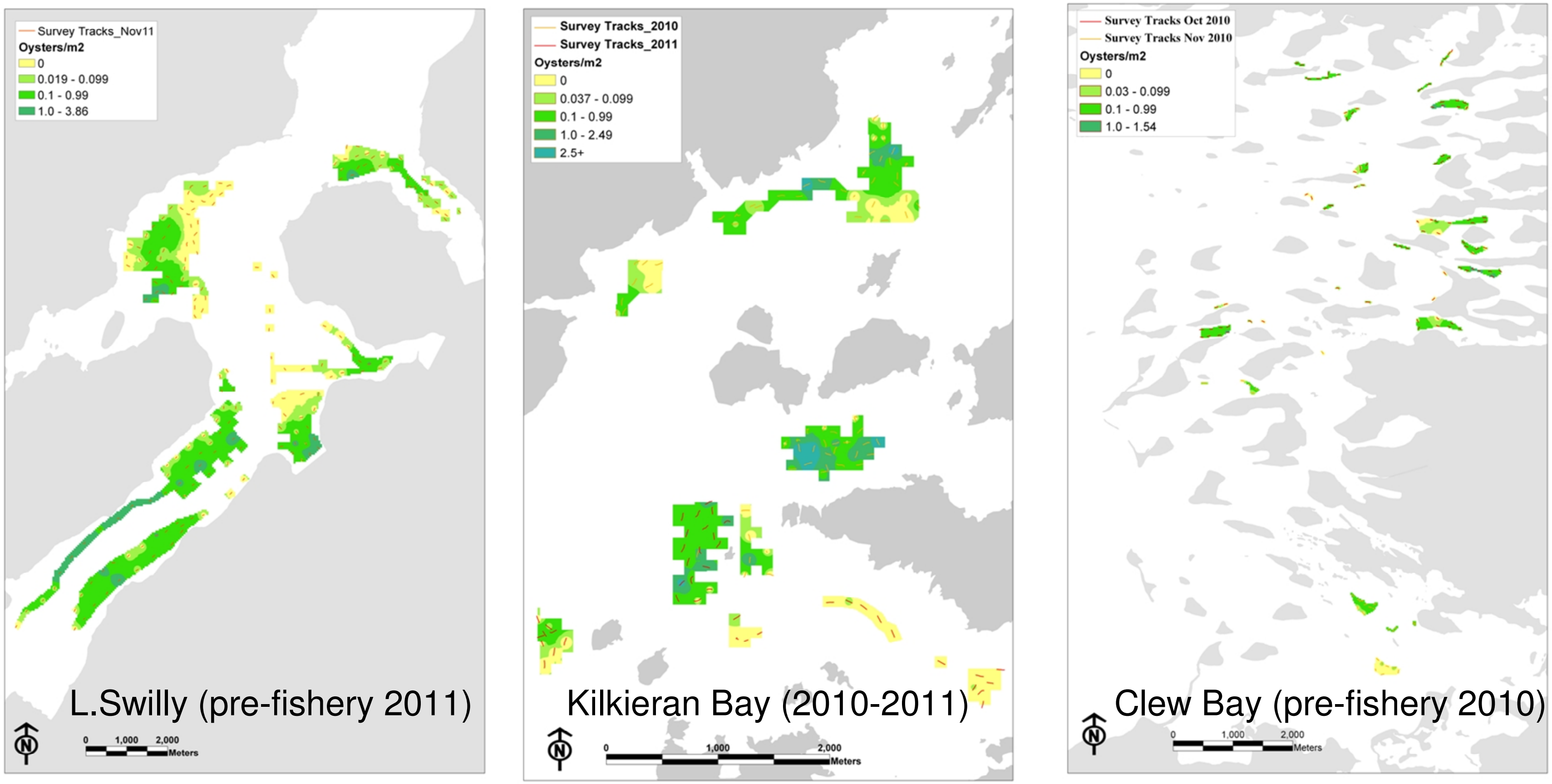

Figure 5. Distribution and density of native oysters in 3 sites surveyed between 2010 and 2012. Interpolation of densities is restricted to areas where there is sufficient survey information. The full extent of all oyster patches was not identified in Clew Bay.

3.3 Biomass

From the targeted surveys undertaken in the seven sites during 2010 to 2012 (Table 4 and Figures 4 & 5), it is apparent that the highest densities and majority of the biomass of native oyster were found in Inner Tralee Bay. Biomass in this bed varied from 982-1278 tonnes between 2010 and 2012. Relative to inner Tralee Bay biomass in other areas was much lower. In decreasing order, biomass was 124±56 tonnes in L. Swilly, 99±61 tonnes in outer Tralee Bay, 53±7 tonnes in Kilkieran Bay, 34±21 tonnes in Galway Bay, 25±6 tonnes in Blacksod Bay and 14±2 tonnes in Clew Bay (Table 5).

Table 5. Biomass (tonnes) ± 95% C.I. of oysters from 14 surveys at 7 sites surveyed in 2010-2012

Site	2010/2011		2011/2012	
	Pre-fishery	Post-fishery	Pre-fishery	Post-fishery
Inner Tralee Bay	982±224	Not estimated	1278±1059	1329±680
Outer Tralee Bay	99±61		69±33	
Kilkieran Bay	49±10	13±4		
Blacksod Bay		25±6		
Clew Bay	14±2			
Galway Bay		34±21		28±12
Lough Swilly		40±16	124±56	

3.4 Biological characteristics

3.4.1 Shell height-weight

Exponents (b) of the shell-height weight relationship were 3.70, 3.17 and 2.91 in inner Tralee Bay, Galway Bay and outer Tralee Bay, respectively (Figure 6). The common exponent for these 3 sites was 3.225. The exponents (b) of the regression of log (size) on log (weight) were significantly different (Analysis of covariance, $F=6.5$, $df = 2$, $p<0.01$). At smaller shell heights, oysters in Inner Tralee Bay were lighter than in Galway Bay but, at larger shell heights, inner Tralee Bay oysters were heavier. Changes in shape during growth account for these changes and may be related to oyster density on the seabed or differences in environmental conditions during growth.

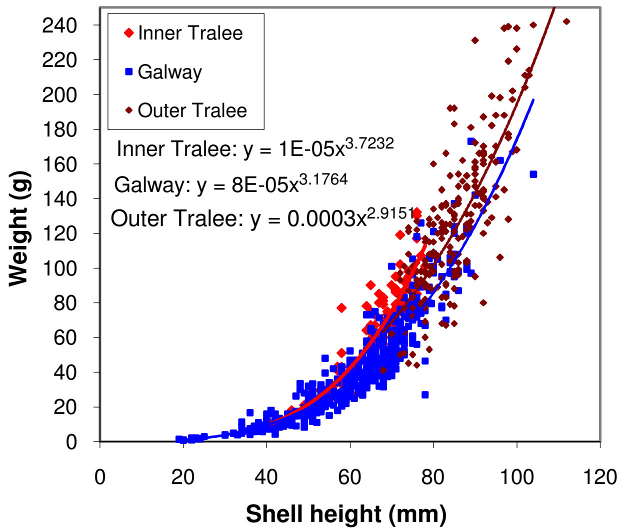

Figure 6. The relationship between size and weight of oysters in 3 oyster beds in 2011

3.4.2 Size distribution and recruitment

Oyster size distributions were generally uni-modal or, more rarely, bi-modal (Figure 7). Modal size in outer Tralee Bay and Blacksod Bay was larger than at other sites. Here, the percentage of oysters over 75mm was 91% in 2010 in outer Tralee Bay and 54% in Blacksod Bay, compared to 23% in Clew Bay, 18 and 22% in Kilkieran Bay, 21% in Inner Tralee Bay prior to the fishery in 2010, 4-12% in Inner Tralee Bay in 2011-2012, 8-11% in Galway Bay and 3-6% in L. Swilly. These differences are likely due to a combination of recruitment events, which adds small oysters to the stocks, and fishing which removes oysters over 76mm. The size distributions show an absence of any significant spat settlement, probably since 2008, in Kilkieran, Clew Bay and Blacksod and, possibly 2009, in Galway Bay and L. Swilly. In Inner Tralee Bay, settlement was strong in 2010 as shown by a mode at 25-30mm in survey data for autumn of 2011. There was also evidence of a 2010 settlement in outer Tralee Bay in the Feb 2012 survey data.

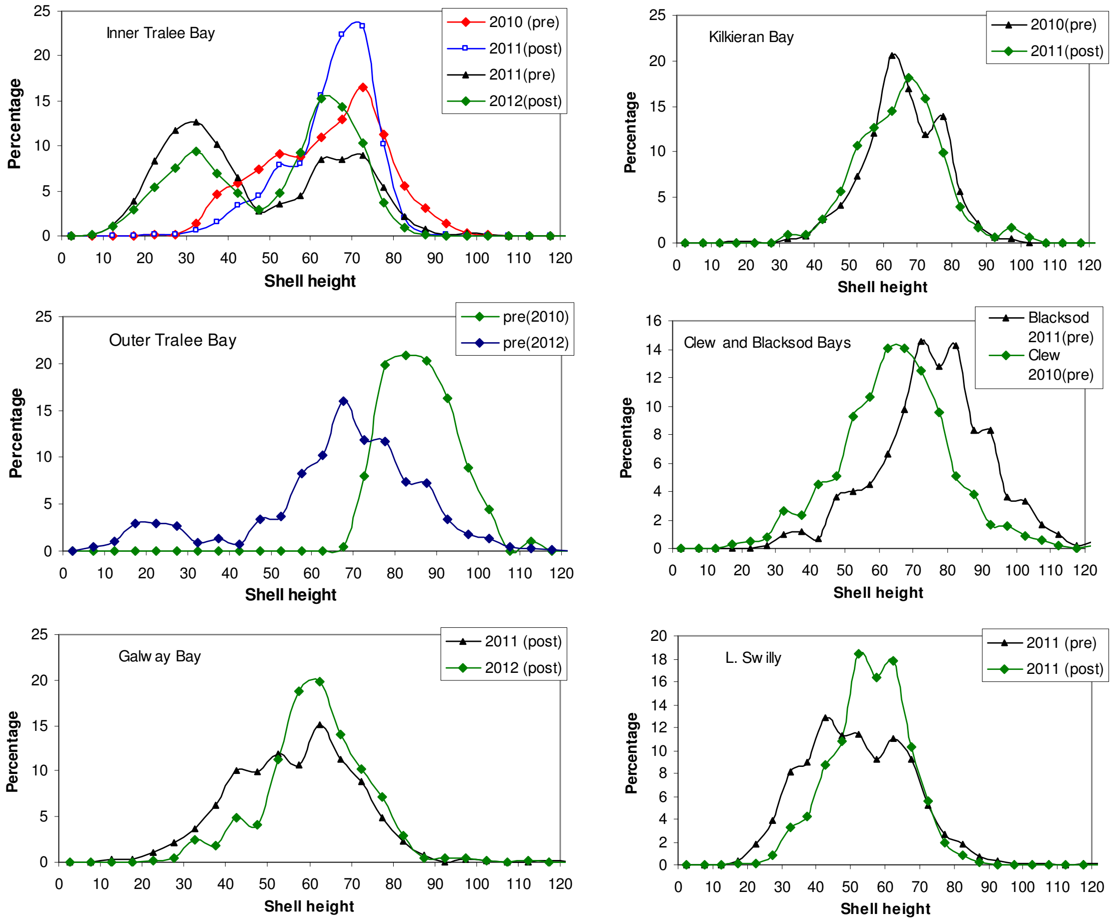

Figure 7. Size distribution (shell height) of oysters in 7 oyster beds sampled in 2010-2012 before and after seasonal fisheries that occurred at each site. Note different scales on y axis.

3.4.3 Growth

There was evidence of an age signal in the size distributions, for ages 1-2, from the 2010-12 survey data. Barry (1981) also provided data for oysters in Kilkieran and Tralee Bays which clearly shows that the modal size of 0+ oysters in Autumn surveys is approximately 7.5mm (Table 6). Based on these data, the first mode in the Galway Bay data in July 2011 and in Tralee Bay in Sept 2011 and Feb 2012 can be interpreted as aged 1+. From the data in Table 6, compiled from Barry (1981) and the present survey data, and by fixing L_∞ at 120mm, the growth coefficient (k) and size at age zero (t_o) were estimated to be 0.21$year^{-1}$ and 0.23years, respectively (Figure 8). The size at age data for ages 0+ and 1+ also show seasonality in growth which could be incorporated into a seasonalised growth model; data for 0+ and 1+ oysters in Kilkieran (from Barry 1981) and Tralee indicate zero winter growth. The derived growth parameters are very different to those published for oysters beds in England and Wales (Table 7).

Table 6. Size at age data for juveniles *O. edulis*.

Age	Mean	Source	Site	Month
0.33	7.5	Barry 1981	Tralee	Oct
0.67	7.5	Barry 1981	Kilkieran	Feb
1.08	22	This study	Galway	July
1.33	30	This study	Tralee	Sep
1.67	30	This study	Tralee	Feb
2.16	39	This study	Galway	July
3.24	50.6	This study	Galway	July
4.30	68	This study	Galway	July

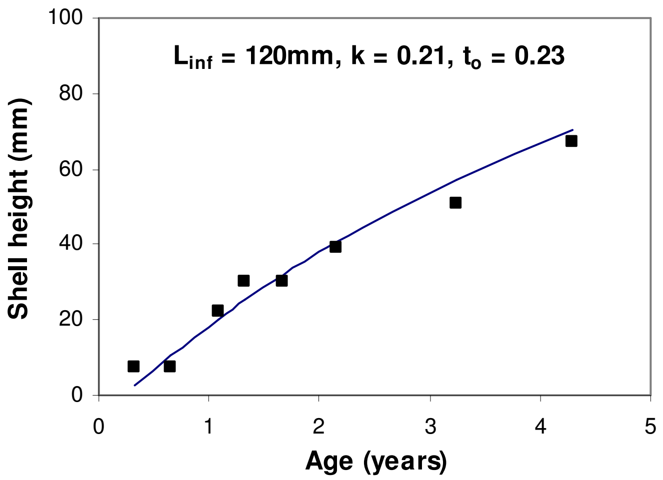

Figure 8. Size at age and fitted vonBertalanffy growth curve for *O. edulis* based on data from Table 14. Zero winter growth of 0+ and 1+ oysters is evident.

Table 7. Growth rate parameters for oysters from sites in England and Wales compared to those derived in the present study. The estimate for Wales is derived from size at weight data presented in Walne (1958) and converted to shell height using the size weight relationship in Figure 6 and using size at age 0.3 of 7mm which is clear in size distribution data.

Site	k	L_∞	Source
Blackwater (England)	0.41	93	Richardson et al 1993
Solent (England)	0.46	72	Richardson et al 1993
Fal (England)	0.35	80	Richardson et al 1993
Conway (Wales)	0.45	95	derived from Walne 1958
Ireland	0.21	120	This study

3.4.4 Mortality

Estimates of total mortality (Z), derived from the length converted catch curves, were generally higher in post-fishery surveys (Z=1.37, n=7) than in pre-fishery surveys (Z=1.03, n = 6) (Table 8). This reflects the depletion of oysters over 76mm by the fishery. In Inner Tralee Bay the differences in Z between pre and post fishery surveys was 0.93 and 0.88 in 2010/2011 and 2011/2012 respectively. This represents mortality (removal) of 58-60% of oysters, recruited to the fishery, during the fishing season.

3.4.5 Biomass per recruit (single cohort)

Both the biomass per recruit and the size at peak biomass of a recruiting cohort are lower at higher levels of M (Figure 9). This is intuitive; the overall biomass that develops will be less when M is higher and maximum biomass will occur at a lower shell size because fewer oysters are surviving and contributing to biomass at large shell size. At values of M <0.4 and at F = 0, the maximum biomass of a cohort peaks above the MLS of 76mm (Figure 9). At M>0.4 biomass peaks below the MLS and will already have declined before the cohort is fished. In this scenario reducing the MLS would provide for improved yields in reducing the time period during which oysters are exposed to M only. F of 0.9, which is the value suggested by comparing Z estimates in pre and post fishery surveys in Inner Tralee Bay, reverses the increase in biomass that would occur if F was zero especially at lower values of M (Figure 9). At all values of M, F of 0.9 produces an exponential decline in biomass in relation to shell height (and age). This is reflected in the survey size distribution data of oysters over 76mm (Figure 7). At high values of M the biomass available to the fishery, and yields, above the MLS will be very low.

Table 8. Total mortality rates (Z) derived from length converted (to age) catch curves for each survey and using growth parameters in Figure 8. Seasonalised growth parameters c = 1.0 and winter-point = 0.5 were included to minimise bias in Z estimates caused by seasonal growth.

Site	2010/2011		2011/2012	
	Pre-fishery	Post-fishery	Pre-fishery	Post-fishery
Inner Tralee Bay	1.33	2.26	1.18	2.06
Outer Tralee Bay	1.09		Not estimated	
Kilkieran Bay	1.23	0.85		
Blacksod Bay		0.54		
Clew Bay	0.64			
Galway Bay		1.32		1.04
Lough Swilly		1.57	0.70	
Average	**1.07**	**1.30**	**0.94**	**1.55**

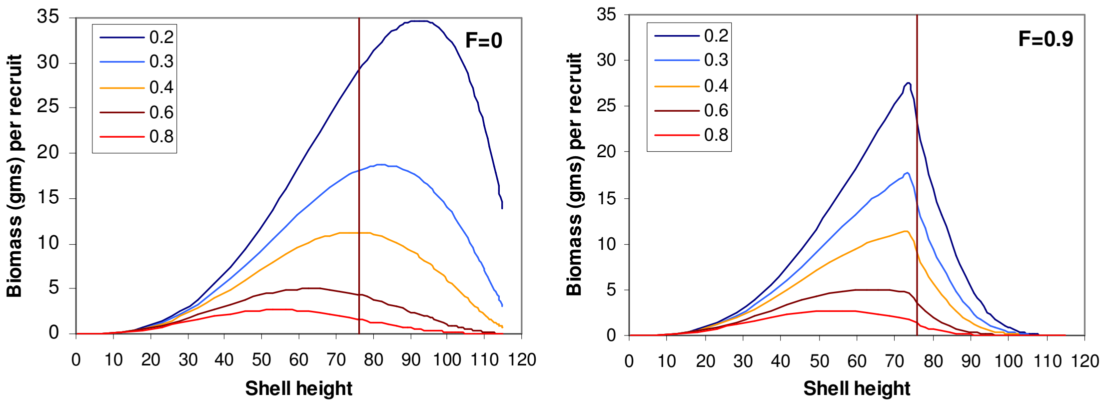

Figure 9. Evolution of biomass per recruit of a single cohort of oysters at different levels of M (0.2-0.8) with no fishing and with annual F of 0.9 above the MLS of 76mm. The size weight relationship for Galway oysters Figure 6 and growth parameters in Figure 8 were used in the model.

Co-occurrence of native and Pacific oyster

Pacific oysters (*Crassostrea gigas*) were common only in L. Swilly. In Galway Bay, although Pacific oysters are grown on the seabed in the FO area, very few were captured outside this area in the public oyster beds. In L. Swilly, on the other hand, Pacific oysters were widespread and abundant.

In March 2011, Pacific oyster densities in L. Swilly ranged from 0-5m^{-2} and the total number estimated in the survey area was 1.07 million oysters. In November, densities ranged from 0-8m^{-2}, density at the majority of stations was below 3m^{-2} and the total number in the survey area was estimated to be 5.64 million oysters. The average size was 81±28mm, in March 2011, and 84.9±25.9mm, in November 2011. It is likely that a number of age classes were present in the population.

The distribution of Native and Pacific oysters overlapped but Pacific oysters tended to be dominant in intertidal areas and shoreward of native oysters with the latter becoming more common at the edge of channels and in shallow sub-tidal areas (Figure 10).

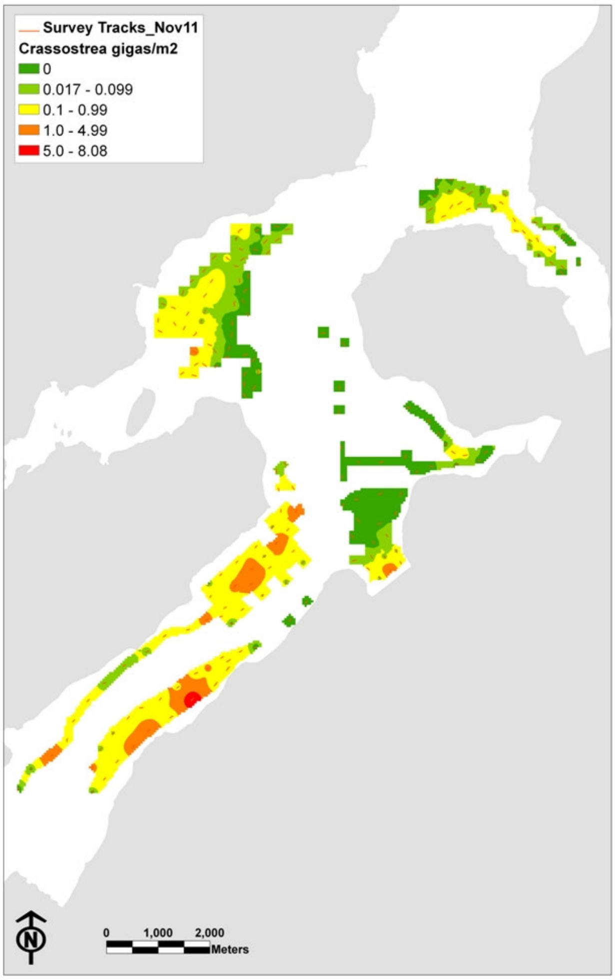

Figure 10. Distribution and density of Pacific oyster in Lough Swilly in November 2011.

4 Discussion

A series of 14 surveys in 7 of the main oyster producing areas in Ireland in 2010-2012 showed that population densities of oysters and total biomass were low. Over 80% of the national oyster biomass occurred in inner Tralee Bay although this bed represented approximately 14% of the geographic area encompassed by all surveys. This bed also produces the majority of the annual national landings. In sites that are producing oysters commercially such as Tralee Bay, Galway Bay, Kilkieran Bay and Lough Swilly the fishery is reliant on relatively small areas (patches) of oysters rather than on the entire extent over which oysters are distributed i.e. the distribution of commercial densities is quite ‘patchy’ and represents a relatively small proportion of the total area over which oysters are distributed.

Spat settlement and recruitment appears to occur regularly, although perhaps not annually, in inner Tralee Bay, Lough Swilly and Galway Bay but less frequently at other sites. Young of the year oysters, which would be 4-7 months old when the surveys were undertaken, would not have been detected effectively, given the survey methods, which involved sorting, counting and measuring oysters on the deck of the boat. However, if the shape of the size distributions is indicative of past recruitment events then there appears to be missing year classes in all sites.

The proportion of oysters above the MLS (76mm) was generally less than 20%, except in Blacksod Bay and outer Tralee Bay. The proportion over this size was lower in post-fishery than in pre-fishery surveys, as would be expected. The annual mortality of oysters over the MLS, in commercially fished stocks, appears to be approximately 60% (equivalent to the difference in Z estimates of 0.9 for pre and post fishery survey data in Tralee). The MLS is at or above the point at which biomass, from a given settlement, may be at a maximum i.e. it is unlikely that growth overfishing is occurring. However, these estimates are sensitive to rates of growth and mortality used in the analysis. Athough no maturity estimates are available, it is generally known that oysters are mature at sizes significantly below the MLS and possibly at shell heights of 30mm in Galway Bay for instance (O’Neill pers. com). The apparently high exploitation rates of oysters over 76mm may, therefore, not necessarily be problematic. However, where spawning stocks are already low and where recruitment is infrequent, which is the case in most sites, high annual exploitation rates puts stocks at risk from further depletion.

Although the data on density (and biomass) is very sensitive to dredge efficiency, densities were estimated to be less than 0.5 oysters m^{-2} at the majority of survey stations including some stations in inner Tralee Bay. Low densities may limit reproductive success in oysters. Although fertilisation occurs internally, in the pallial cavity, the eggs are fertilised by externally released sperm from neighbouring oysters. If the density of neighbouring oysters is very low then sperm dilution may reduce fertilisation success. This *allee* effect at low densities could lead to negative per capita growth rate and, theoretically, could lead to extinction (Courchamp *et al.*1999). The critical density threshold for avoidance of *allee* effects in oysters in not known. *Allee* effects may be compounded by parasite induced mortality although the low density of oysters may also limit the prevalence of *Bonamia* in these populations. The net effect depends on the virulence of the parasite, the transmission rates at low density and how these interact with density dependent *allee* effects on fertilisation (Deredec and Courchamp 2006).

Oyster growth rates are known to vary across sites in relation to temperature (Hall 1985) and tidal exposure among other factors (Walne 1958). The growth rate parameters, estimated in this report, are very different to those provided by Richardson *et al*. (1993) or estimates derived from Walne (1958) for oysters in England and Wales, where L_∞ varied from 72-93mm and the growth coefficient (k) ranged from 0.35-0.46. The size at age estimates provided here are within the range predicted by Hall (1985) who used a multiple regression model, incorporating temperature from two contrasting sites, to predict growth rates. Richardson *et al*. (1993) verified age and growth by sectioning shells and producing acetate peels to visualise annual growth rings while Walne (1958) followed the growth of oysters of known age over time. Nevertheless, oysters up to 120mm shell height were present in the survey data reported here indicating that L_∞ must be substantially higher than that reported for oysters in England and Wales. The shell height at which maximum yield is expected (L_{opt}, Holt 1958) is, as shown in the evolution of biomass simulation, sensitive to growth and mortality rates. Froese and Binohlan (2000), reporting on life history invariants in marine fish, indicated that the ratio of L_{opt} / L_∞ is predictable and averages 0.63. The ratio of MLS/L_∞ in Irish oysters is, coincidentally, also 0.63 suggesting that the current MLS is appropriate (close to L_{opt}) and, as such, that M may be close to 0.4. However, the Froese and Binohlan (2000) L_{opt} / L_∞ ratio is for finfish and cannot substitute for improved data on growth and mortality estimates for Irish oysters, including incidental mortality caused by dredge contact with undersized oysters. Given that temperature, in particular, has a strong effect on growth rate the growth parameters provided in this report should be taken as indicative only of the possible size at age of Irish oysters. Site specific growth models, which incorporate temperature, would improve stocks assessments and allow optimal, and if necessary, site specific MLS to be estimated.

A further implication of low oyster density is the level of dredging required to catch the annually agreed TACs. This is further exacerbated by the low dredge efficiency and the high minimum landing sizes relative to the size composition of oysters in the stocks. Generally, less than 20% of oysters were over the MLS, densities were usually less than $0.5m^{-2}$ and dredge efficiency was estimated to be 35%. Catch returns per unit of dredging under these conditions are very low and the fishing process is inefficient. A more productive fishery management strategy would be to restore biomass (and density), reduce minimum landing size (particularly where M>0.4) and use efficient dredges under a TAC regime.

A number of management initiatives can be established relatively easily that would promote the recovery of biomass and population density in Irish oyster stocks. The basis for recovery must be founded in protecting or, if necessary, establishing a spawning stock at densities that ensure high fertilisation success and that results in significant larval production when environmental conditions allow for this. Spawning events do not, however, necessarily lead to larval settlement either because the larval condition is poor and there is high mortality of larvae or because larvae cannot find suitable substrate on which to settle. Settlement can be enhanced by management interventions. Settling oysters need relatively clean (unsilted) substrates on which to settle (UMBS, 2007). The method chosen for the maintenance and provision of that substrate is, however, critically important. Typically, either the ground is harrowed to uncover new clean shell, and to kill epifauna, or new clean shell is spread over the bed (cultching) (Waugh 1972). Waugh

(1972) undertook systematic field experiments to assess the relative efficacy of harrowing, cultching or fallowing (no activity) on larval settlement in the Rivers Couch and Fal in England. Harrowing can only be effective if there is significant shell buried in the sediment that can be brought to the surface and if the shell remains free of silt for the period prior to larval settlement. Waugh (1972) found that harrowing was ineffective; there was no increase in shell availability after harrowing and harrowed areas quickly became silted. These areas did not receive as much settlement as areas that were fallowed or especially those areas that were culched with mussel shell. Barry (1981) demonstrated the same beneficial effect of cultching with mussel shell in Kilkieran Bay.

Management interventions to restore and maintain oyster stocks need to taken into account the conservation objectives now being described for oyster habitat in SACs (NPWS 2011). Spatial extent, structure and function of these habitats need to be maintained. As oyster, logically, is described as a characterising species of these habitats, maintenance or recovery of oyster populations in these habitats is a requirement if such habitats are to achieve and maintain favourable conservation status under reporting for Article 17 of the Habitats Directive. Guidance (NPWS 2011a,b) indicates that significant persistent disturbance should occur on either less than 15% of the habitat or, if it is above this threshold, then the disturbance should not be persistent (on-going or frequent) or significant (leading to change in the characterising fauna). The persistence and significance of disturbance should be assessed in relation to habitat resilience. Management also needs to consider the conservation objectives for other characterising species that occur in oyster habitat.

Habitat 'maintenance' operations such as harrowing can have negative effects on oyster ground and on oysters and may be incompatible with habitat conservation objectives. Harrowing and commercial dredging activity both lead to shell breakage and gradual homogenisation of habitat, loss of small scale structural relief, increased dominance by smaller species and decline in epifauna and burrowing megafauna (Sewell *et al.*. 2007, Thrush *et al.*. 1998, 2001, Collie *et al.*. 1996, Kaiser *et al.*. 2000). These changes may be contrary to the physical and topographic conditions required for larval settlement. Although un-silted substrate is important the angle of presentation of the substrate and small scale relief on the seabed may be important in providing suitable hydrodynamic conditions, at very local scale, that stimulate larvae to settle (Cranfield 1968). Increasing and maintaining habitat complexity, shelliness and relief is, therefore, important. Regular contact with dredges and harrows also causes mortality of oysters that are actively growing and can stunt growth in surviving oysters (Waugh 1972). Recovery from dredging impact is habitat dependent (Foden *et al.* 2010). Long term modification of oyster reef habitat was described by Cranfield et al (1999) in New Zealand who indicated that restoration of oyster also depended on restoration of habitat. Rothschild *et al.* (1994) described long term habitat degradation and a parallel decline in oysters in Chesapeake Bay which was associated with intensive fishing and over-stocking.

Translating conservation objectives for oyster habitat into management objectives for oyster fisheries is an important task for conservation authorities and oyster fishery managers alike in SACs where oysters are described as characterising species. Given that current biomass and density are low and recruitment is irregular, neither the conservation objectives or fishery objectives are being met i.e. there is a lost production to the fishery and in large areas of oyster habitat oyster is not a dominant and characterising species. Recovery of biomass is, therefore, a common objective but the means of doing so should consider other aspects of habitat structure and function that are also protected by the conservation objectives. Cultching and maintenance of habitat complexity and 'shelliness' would seem to be more acceptable and effective in this regard than harrowing or other forms of ground 'cleaning'. Closed areas may be of benefit in allowing higher densities of oyster to develop, to avoid *allee* effects and to allow habitat complexity to recover. Measures that increase larval production and that promote settlement, leading to increase in oyster density and habitat shell content, would seem to be compatible with both conservation objectives and fishery management objectives.

Management of threats to native oyster beds will also be important in optimising recovery potential. These include freshwater drainage which may increase freshwater volume flow through estuaries, urban development and associated changes in microbiological and viral status of water and introduction or management of non-native species, which pose a threat to oyster, such as the Slipper limpet (*Crepidula fornicata*) and Pacific oyster. Competition with introduced species, such as Pacific oyster, is a realised threat to the maintenance of native oyster beds as shown here in L. Swilly. The surveys showed that large areas of previous native oyster bed had high densities of Pacific oyster in some areas to the exclusion of native oyster. An intensive commercial fishery for Pacific oysters was sustained in 2010 and 2011 in areas of the Lough showing that, locally, biomass of this species was high. This is a recent development stimulated by higher market prices for Pacific oysters but also because high catches are possible. O'Sullivan (2001) did not report Pacific oysters in L. Swilly suggesting that Pacific oyster has, recently, expanded in the Lough. Successful control of that expansion will be important for the recovery and maintenance of native oyster.

From a national perspective the commercial viability of oyster fisheries and prospects for maintenance of populations could be considered to be at significant risk; biomass is concentrated in inner Tralee Bay, biomass is very low and dispersed in other sites, catch rates are low, recruitment is irregular, there are pressures from disease and non-native species, fisheries operate in areas where stocks are depleted, scientific advice is rarely incorporated into regulation of seasonal oyster fisheries and there are generally no fishery management plans with explicit objectives, harvest control rules and reference points in operation. There are exceptions, such as inner Tralee Bay, where annual survey data is being used to define total allowable catch. A management plan has been drafted for the L. Swilly oyster fishery that includes closed areas for protection of spawners, a proposal to cultch areas to promote larval settlement and closure of fisheries in areas where oyster density is low. Managing the recovery of native oyster populations is a more feasible project than restoration of stocks that have gone extinct as has occurred in many areas of the UK (Shelmerdine and Leslie 2009, Laing *et al.* 2006). Fishery management plans have a vital role to play in this recovery.

5 References

Anon 2005. Epizootic investigation into the detection of Bonamiosis in native oysters in a new area in Ireland during Spring 2005: statutory sampling (91/67/EEC). Marine Institute, Rinville, Oranmore, Co. Galway, 45pp.

Barry, M.D. 1981. Distribution and ecology of oysters, *Ostrea edulis* (L.) in Kilkieran and Bertraghboy Bays, Connemara, Co. Galway. Irish Fisheries Investigations, Series B, 24, 3-18

Browne, R., Norman, M., Casburn, P. and Breathnach, S. 2006. An oyster (*Ostrea edulis*) survey undertaken in Setpember and October 2006. Draft report to Comharcumann Sliogeisc Conamara, Kilkieran, Connemara, Co. Galway, 27pp (unpublished).

Coleman, C. F. and Williams, S.L. 2002. Overexploiting marine ecosystem engineers: potential consequences for biodiversity. Trends in Ecology and Evolution 17(1), 40-44.

Collie, J.S., Escanero, G.A. and Hunke, L. 1996. Scallop dredging on Georges Bank: photographic evaluation of effects on benthic fauna. ICES CM 1996/Mini:9

Courchamp, F., Clutton-Brock, T. and Grenfell, B. 1999. Inverse density dependence and the allee affect. Trends in Ecology and Evolution, 14(10), 405-410.

Cranfield, H. 1968. An unexploited population of oysters, *Ostrea lutaria* Hutton, from Foveaux Strait. New Zealand Journal of Marine and Freshwater Research, 2, 183-203.

Cranfield, H., Michael, K. and Doonan, I. 1999. Changes in the distribution of epifaunal reefs and oysters during 130 years of dredging for oysters in Foveaux Strait, southern New Zealand. Aquatic Conservation: Marine and Freshwater Ecosystems, 9(5), 461-483.

Deredec, A. and Courchamp, F. 2006. Combined impacts of *allee* effects and parasitism. Oikos, 112, 667-670.

Foden, J., Rogers, S.I. and Jones, A.P. 2010. Recovery of UK seabed habitats from benthic fishing and aggregate extraction – towards a cumulative impact assessment. Marine Ecology Progress Series, 411, 259-270.

Froese, R. and Binohlan, C. 2000. Empirical relationships to estimate asymptotic length, length at first maturity and length at maximum yield per recruit in fishes, with a simple method to evaluate length frequency data. Journal of Fish Biology, 56, 758-773.

Hall, S. 1984. A multiple regression model of oyster growth. Fisheries Research 2, 167-175.

Holt, E.W.L. and Hillas, A.B.E. 1905. Preliminary report on experiments in oyster culture on the west coast of Ireland. Annual report of Fisheries, Ireland, 1902-3, Part II, Appendix VIII, 215-228.

Holt, S.J. 1958. The evaluation of fisheries resources by the dynamic analysis of stocks and notes on the time factors involved. ICNAF Special Publication, 1, 77-95.

Kaiser, M.J., Ramsay, K., Richardson, C.A., Spence, F.E. and Brand, A.E. 2000.Chronic fishing disturbance has changed shelf sea benthic community structure. Journal of Animal Ecology, 69, 494-503.

Kennedy, R.J. and Roberts, D. 1999. A survey of the current status of flat oyster in Strangford Lough, Northern Ireland, with a view to the restoration of its oyster beds. Biology and Environment, 99B, 79-88.

King, M. 1995. Fisheries Biology, Assessment and Management. Fishing News Books, Oxford, 341pp.

Laing, I., Walker, P. and Areal, F. 2006. Return of the native – is European oyster (*Ostrea edulis*) stock restoration in the UK feasible? Aquatic Living Resources, 19, 283-287.

McArdle, J.F., McKiernan, F., Foley, H. and Hugh-Jones, D. 1991. The current status of *Bonamia* disease in Ireland. Aquaculture. 93, 273-278.

NPWS 2011a. Conservation objectives Lough Swilly SAC 002287, Lough Swilly SPA 004075, Version 1.0, 41pp.
http://www.npws.ie/protectedsites/specialareasofconservationsac/loughswillysac/

NPWS 2011b. Lough Swilly SAC (site code:2287). Conservation objectives supporting document – marine habitats. Version 1, 12pp. National Parks and Wildlife Service, Ely Place, Dublin 2.

Orton, J.H. 1940. Effect of the severe frost of the winter of 1939-40 on the fauna of the Essex oyster beds. Nature, 145, 708-709.

OSPAR 2009. Background document for *Ostrea edulis* and *Ostrea edulis* beds. OSPAR Biodiversity Series 428/2009, 22pp.

Pauly, D. 1990. Length-converted catch curves and the seasonal growth of fishes. ICLARM Fishbyte, 8(3), 33-38.

Powell, E.N., Kraeuter, J.N., Ashton-Alcox, K.A. 2006. How long does oyster shell last on an oyster reef. Estuarine and Coastal Shelf Science, 69, 531-542.

Richardson, C.A., Collis, S.A., Ekaratne, K., Dare, P. and Key, D. 1993. The age determination and growth rate of the European flat oyster *Ostrea edulis* in British waters determined from acetate peels of umbo growth lines. ICES Journal of Marine Science, 50. 493-500.

Rothschild, B.J., Ault, J.S., Goulletquer, P., Heral, M., 1994. Decline of the Chesapeake Bay oyster population: a century of habitat destruction and overfishing. Marine Ecology Progress Series 111, 29– 39.

Sewell, J., Harris, R., Hinz, H., Votier, S., Hiscock, K. 2007. An assessment of the impact of selected fishing activities on European marine sites and a review of mitigation measures. The MBA and University of Plymouth, report SR591, ISBN 0903941694

Shelmerdine, R. L. and Leslie, B. 2009. Restocking of the native oyster, *Ostrea edulis*, in Shetland: habitat identification study. Scottish Natural Heritage Commissioned Report No. 396.

Smyth, D., Roberts, D., Browne, L. 2009. Impacts of unregulated harvesting on a recovering stock of native oyster. (*Ostrea edulis*). Marine Pollution Bulletin, 58, 916-922.

Todorova, V., Micu, D. and Klisurov, L. 2009. Unique oyster reefs discovered in the Black Sea. Comptes rendus de l'Academie bulgare des Sciences, 62(7), 871-874.

Thrush, S.F. et al. 1998. Disturbance of the marine benthic habitat by commercial fishing: impacts at the scale of the fishery. Ecological Applications 8, 866-879.

Thrush, S.F. et al. 2001. Fishing disturbance and marine biodiversity: role of sediment structure in simple soft bottom sediments. Marine Ecology Progress Series, 221, 255-264.

UKBAP (1999). Tranche 2 Action plans. Maritime species and Habitats.
http://jncc.defra.gov.uk/PDF/UKBAP_Tranche2-ActionPlans-Vol5-1999.pdf

University Marine Biological Station 2007. Conservation of the native oyster *Ostrea edulis* in Scotland. Scottish Natural Heritage Commissioned Report, No. 251 (ROAME No. F02AA408)

Walne, P.R. 1958. Growth of oysters (*Ostrea edulis* L.). Journal of Marine Biological Association of the United Kingdom, 37, 591-602.

Waugh, G.D. 1972. Settlement of *Ostrea edulis* (L.) in relation to the cultivation of oyster grounds. Fishery Investigations London, Series II, 27, 2, 33pp.

Went, A.J. 1962. Historical notes on the oyster fisheries of Ireland. Proceedings of the Royal Irish Academy, C, 62, 195-223.

Whilde, A. 1973. Evaluating survey of oyster beds in Galway Bay and along the County Galway coast. Resource Record Paper, 24, Irish Sea Fisheries Board, Fisheries Development Division, 18pp.

www.marine.ie

ISSN 1649 0037

www.marine.ie

HEADQUARTERS & LABORATORIES
MARINE INSTITUTE
Rinville
Oranmore
Co. Galway
Tel: +353 91 387 200
Fax: +353 91 387 201
Email: institute.mail@marine.ie

MARINE INSTITUTE REGIONAL OFFICES
MARINE INSTITUTE
80 Harcourt Street
Dublin 2
Tel: +353 1 4766500
Fax: +353 1 4784988

MARINE INSTITUTE
Furnace
Newport
Co. Mayo
Tel: +353 98 42300
Fax: +353 98 42340