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The scientific implications of the EU Project WESTHER (Q5RS - 2002 – 01056) to the assessment and management of the herring stocks to the west of the British Isles.

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Abstract

WESTHER's overall goal was to describe the population structure of herring stocks to the west of the British Isles, to enable the production of a set of improved guidelines for the conservation and management of biodiversity and stock preservation by incorporation of the findings into the assessment processes for western herring. Analysis of a multi-disciplinary suite of characters was carried out on herring collected from spawning aggregations, from nursery areas and from adult non-spawning, feeding aggregations in the study area. The results revealed temporally distinct spawning grounds in the area, with each of them being populated by a group of herring which, in general, have a certain level of site fidelity. There was a clear distinction of many of the different juvenile samples. There was, however, strong evidence that juveniles from separate spawning areas mixed in some of the nursery areas sampled. There was also evidence to suggest mixing of adults from separate spawning components, especially in the area to the west of Scotland (VIa North). The science, therefore, suggests links between the areas, with fish spawning in different areas mixing, to varying extents, on feeding grounds and, therefore, fish from each spawning aggregation do not remain discrete on their feeding grounds. The results from WESTHER suggest that under the current stock assessment units, two basic assumptions of stock assessment (the stock is a closed unit, and the data used in assessments are representative of the entire stock) are violated. Alternative recommendations for the combination of stocks are discussed with reference to their assessment and management.

Keywords: assessment and management; herring, multi-disciplinary approach, stock components

Introduction

Historical background to stock assessment and management of herring to the west of the British Isles

Seasonal fisheries for herring take place in many different areas around the coast of the west of the British Isles (Scotland, Ireland, northwest England, the Isle of Man and Wales). These western herring stocks were considered by ICES for the first time in 1969 (ICES 1970). The assessment and management of the western stocks was considered

necessary due to the possible diversion of effort to these waters because of the decline of the North Sea herring fishery, which ended in a 4-year-closure there from 1977 onwards.

The ICES Working Group recognised two stocks – one inhabiting the area north and north-west of Ireland and west of Scotland and the other inhabiting the area south of Ireland (Celtic Sea). The Working Group did not consider the population in the Irish Sea as a separate stock. The appropriate management units were considered as coincident with ICES Division VIa (west of Scotland and north-west Ireland) and Divisions VIIg-k with the southern part of VIIa (south of 52^{o} 30'N) (Celtic Sea).

TACs for **Division VIa** were set by the North-East Atlantic Fisheries Commission (NEAFC) from 1972 until the closure of the herring fishery in 1978. The fishery was not reopened until July 1981. Despite a considerable fishery being carried out in the adjacent Division VIIb, this herring resource was not assessed analytically, and a precautionary TAC was imposed during the closure time of Division VIa. In 1981 the ICES Herring Assessment Working Group (HAWG) reviewed the fisheries in both areas, along with the available biological information about the stocks. The result was that in 1982 HAWG (ICES 1982) recommended new management units: one for **VIa North** and a second one for **VIa South & VIIb,c**. The rationale was that the fisheries in the two areas were distinct, the fisheries were prosecuted by different countries and there were rather different recent (1970s) patterns of fishing activity in the two areas. These units were adopted by the European Commission (EC) in 1982.

In 1978, at the recommendation to cease fishing in area VIa, the EC requested ICES to examine the **Clyde** populations separately from the rest of VIa. The question revolved around the closure of the fishery on autumn spawning populations and the presence of spring spawners in the Clyde. The HAWG convened in September 1978 to evaluate the position of herring in the Firth of Clyde in relation to neighbouring herring stocks and assess the state of the Clyde stock. The outcome was that the HAWG recommended the Clyde fishery should be treated as a separate management unit to the rest of Division VIa. The first TAC regulation was introduced in 1979 and a number of management regulations were defined in the period following. The first analytical assessment was carried out in 1982. Management of the Clyde has remained separate since 1979.

For the **Celtic Sea**, TACs were first introduced in 1972 and continued until the closure of the fishery in 1977. The important fishery in Division VIIj developed during the 1970s. At that time, however, it was not assessed and was only ascribed a precautionary TAC. The 1981 and 1982 HAWGs examined the biological and fisheries data for the two areas and concluded that the most appropriate management area was a combination of the two. The fishery reopened in 1982 and the stocks in the Celtic Sea (VIIaS, VIIg,h,j,k) have been assessed and managed as one unit (named Celtic Sea and VIIj) ever since. During the early 1990s relatively large catches were taken on the border between areas VIIb and VIIj leading to doubt as to whether these catches belonged to the Celtic Sea or west of Ireland stocks. ICES (1994) recommended that the boundary between the west of Ireland and Celtic Sea management stocks be shifted southward from 52^{o}30'N to 52^{o}00'N. This was never implemented.

The stock in the **Irish Sea** (Division VIIa North (north of 52^{o} 30'N)) was first assessed by UK scientists in 1972 on the basis of two spawning components (Manx and Mourne), and a national quota for that area was introduced in 1972. Although the two components were assessed separately, they were managed as a single stock and one TAC for the whole area was introduced by the EC in 1977. A separate quota was set for the small Northern Irish drift net fishery that took place on the Mourne spawning grounds. Catches of Manx and Mourne components in the mixed fishery were separated based on vertebral counts, however, this method was eventually discarded because it was not thought to be precise enough. So, in 1982 the HAWG concluded it was not possible to assess the Manx and Mourne components separately and combined the two into a single stock assessment.

Much of the decision making behind many of these changes, around Ireland in particular, has been reviewed extensively in a recent publication on "The Herring Fisheries of Ireland" (Molloy 2006).

Throughout the 1970s and 1980s then, the concept of stock was used to deal with fleet based management problems. Major decisions to separate areas and create new stocks were based on fishing patterns and the exploitation by different fleets, not biology. These new stocks were then assessed and often managed separately.

Current assessments

Currently (see ICES, 2007) the putative herring stocks to the west of the British Isles are assessed separately as 1: VIa North; 2: VIaS and VIIb,c; 3: Irish Sea and 4: Celtic Sea and VIIj (Figure 1). Herring in the Clyde is recognized as a separate stock but due to the very low catches, no survey information and the perception of a very low stock size, is not currently assessed analytically. The assessments are undertaken using annually obtained landings, catch- and weight-at-age along with a variety of survey tuning indices for an assessment through the Integrated Catch Analysis (ICA) (see ICES, 2007). In all cases, landings data are assigned to the area (stock) and statistics formulated by area.

In each area there are a number of survey data sets (tuning indices) that are, or could be, used within a Virtual Population Analysis (VPA). In the case of VIa North, there are acoustic survey data (1987, 1991-present) on the summer (July) distribution, biomass and abundance of the stock. This survey covers the area west of 4^{o}W around the shelf southwards to 56^{o}N. In the case of the Celtic Sea and VIIj there are acoustic survey data on spawning stock biomass at or close to spawning (autumn/winter, since 1990, with the exception of 1997). For the Irish Sea acoustic survey data are available, again close to spawning time, on spawning stock biomass. For each acoustic survey biological data are available to determine size-at-age, numbers-at-age etc. In addition there is a larvae production series that also serves as an indicator of the dynamics of the spawning stock. Data exist on the numbers of juvenile herring in the Irish Sea area but this has never been used as a recruitment index due to the known mixing of, at least, Irish Sea and Celtic Sea juveniles (see, e.g., Brophy & Danilowicz 2002). In VIaS and VIIb,c an acoustic survey of the spawning biomass of herring (at spawning time) was initiated in 1999, however, this time series is still too short to be used as a tuning index for this stock.

There were larvae surveys in the Celtic Sea (1978 to 1985 and in 1990), north-west Ireland (1981 to 1988), in the Irish Sea on Douglas Bank (1974 to 1988 and 1989 to 1999) and off the west coast of Scotland (1973 to 1993) (see ICES 1994). Each of these was discontinued for a variety of reasons. In the Celtic Sea multiple cruises throughout the spawning season resulted in reliable indicators of spawning stock (ICES, 1990), however, these surveys were replaced with acoustic estimates of spawning stock size. The north-west Ireland surveys were discontinued because they did not give a realistic estimate of stock size probably because of influx of larvae from adjacent areas, occasionally missed part of the autumn spawning production because of survey timing and no account taken for the winter/spring spawning component that in some years comprised a major component of the commercial catches. The Irish Sea Douglas Bank surveys were discontinued since they did not reflect the dynamics of the spawning stock, probably because the surveys were over a limited area and susceptible to variability caused by relatively minor shifts in peak spawning/hatching time. The west of Scotland acoustic surveys were deemed to give better data on stock biomass and abundance so the larvae surveys were discontinued in 1993. A Larvae Abundance Index (LAI) and Larvae Production Estimate (LPE) were calculated for the west coast of Scotland larvae surveys. These values were used in the assessment, the LAI until 2001. However, in 2002 it was decided that the LAI had no influence on the assessment and it has not been used since.

Over the years there have been problems with the assessment of the various stocks to the west of the British Isles. There has been a series of analytical assessments for VIa North, however, in 2006 this was not accepted due to conflicts between the acoustic survey index and catch data (ICES, 2006). In 1992 the assessment of the Clyde ceased due to the lack of landings and fishery independent survey data. Analytical assessments for VIaS and VIIb,c have not been possible due to the lack of fishery independent survey data; exploratory assessments to show the 'development of the

stock' have usually been presented at the HAWG but have not been accepted. The survey data for the Celtic Sea and VIIj stock have allowed analytical assessments, however, conflicting signals appear to be present in the catch and survey data. As such the assessment has been unstable on occasions, resulting in the most recent analytical assessment not being accepted. The assessment of the Irish Sea stock has been unpredictably unstable resulting in no analytical assessment being accepted by the HAWG for many years.

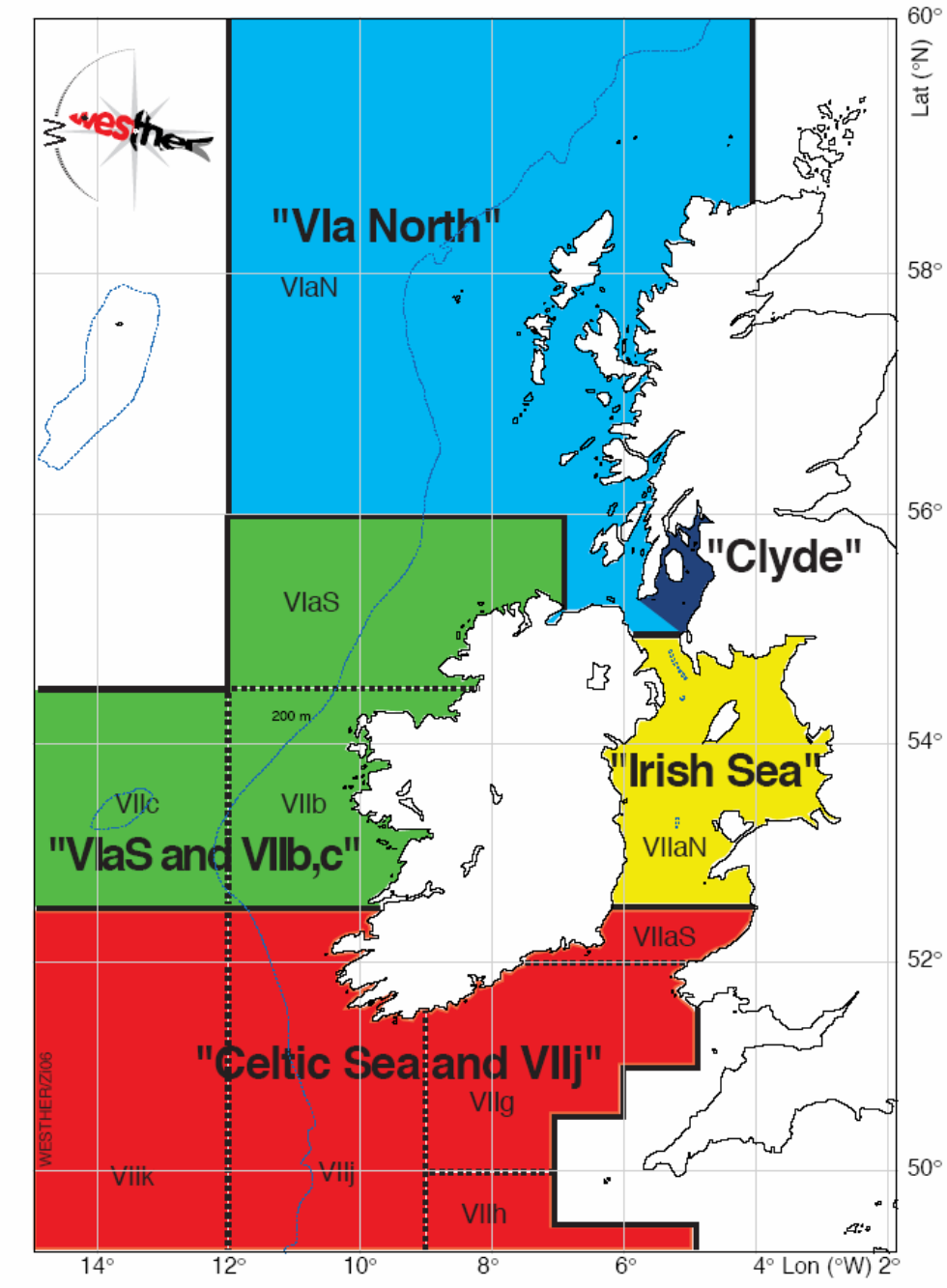


Figure 1. Current defined assessment and management areas for herring stocks to the west of the British Isles.

The most recent situation, i.e., for 2007 (ICES, 2007), is that only one (VIa North) of the herring stocks to the west of the British Isles has an accepted analytical assessment which would allow the derivation of recent stock trends or short term forecasts with sufficient precision.

Current management and fisheries

At present the management is based on the four main fisheries, i.e., Celtic Sea and VIIj, Irish Sea, VIaS and VIIb,c and VIa North. In all cases annual TACs are agreed for each of the fisheries. These are ideally based on scientific advice which is given in accordance with the Precautionary Approach and aim at maintaining the stocks above Bpa wherever possible (if this reference point is defined). An annual TAC is also set for the Clyde, in spite of no existing target fishery.

The VIa North fishery operates throughout the year, and is primarily a winter to summer fishery, i.e., not targeting spawning aggregations. This fishery is linked to the local mackerel fishery in the area and the North Sea herring fishery in the adjacent management area to the east. The fishery in the Celtic Sea and VIIj is primarily a fishery prosecuted on spawning aggregations. However, in the most recent years there has been the inclusion of a summer, 'offshore' fishery. In the Irish Sea and in VIaS and VIIb,c the fisheries tend to be on spawning aggregations.

TAC constraints are set for each 'stock' or area (the management unit) and in general these fisheries are managed at the regional level and prosecuted by discrete 'local fleets'. The exceptions are the VIa North and the VIIj offshore fisheries where international fleets are important. In most cases the fleet sizes vary, both in terms of the numbers of vessels taking part in the various fisheries and the size and capacity of those vessels.

In addition to TAC constraints there are a number of other management measures currently enforced in the Celtic and Irish Seas. The Republic of Ireland's fisheries for both the VIaS and VIIb,c and Celtic Sea and VIIj stocks are managed by local committees. These committees each have a set of local management objectives (ICES, 2007).

In the Celtic Sea and VIIj the fishing season is considered as running from 1st April to the 31st of March the following year. The fishery generally opens around 1st October each year to target the fish when inshore for spawning. Recently, the fishery has remained open throughout to allow vessels to target fish outside the spawning seasons when the fish are of better quality and marketability. The spawning grounds are protected by rotating box closures implemented under EU legislation. In addition to these, one box was voluntarily closed in the recent seasons. This initiative was instigated by the Irish Southwest Pelagic Management Committee to afford extra protection to first time spawners. The Irish Southwest Pelagic Management Committee was established to manage the Irish fishery for this herring stock. It therefore has responsibility for management of the entire fishery for this stock at present.

In the Irish Sea the area around the Mourne coast is permanently closed to herring fishing with a derogation for a gillnet fishery, this is designed to protect the Mourne spawning component. There is a spawning ground closure (annually 21st September to the 15th November) to the east of the Isle of Man to protect the Manx spawning component. The final measure is a year round closed area for fishing juvenile herring in the eastern Irish Sea, up to 12 nautical miles from the coastline. This is a closure designed to protect the juveniles. Republic of Ireland boats are also banned from fishing for herring to the east of the Isle of Man. The management of herring in the Clyde is complicated by the presence of two spawning components that are not separated currently; a resident spring-spawning component and the immigrant autumn spawning component. Management strategies have been directed towards rebuilding the highly depleted spring-spawning component to historical levels. The measures which remain in force in order to protect the indigenous spring-spawning component are: a complete ban on herring fishing from 1st January to 30th April; a complete ban on all forms of active fishing from 1st February to 1st April on the Ballantrae Bank spawning grounds, to protect the demersal spawn and prevent disturbance of the spawning shoals; a ban on herring fishing between 00:00 Saturday morning and 24:00 Sunday night.

In VIaS and VIIb,c the fishing season is considered to run from late autumn into the spring. It opens on the 1st October and closes around the end of March the following year. Here individual vessels have individual quotas. In 2000 the Irish Northwest Pelagic Management Committee was established to deal with the management of the VIaS and VIIb,c stock.

In VIa North, there is an area closure, commonly called “The Butt of Lewis Box” from 31st August to 15th September, designed as a measure to protect spawning fish. The regulation was adopted in 1986. Also, Republic of Ireland vessels do not participate in the VIa North fishery until after the 1st October; nor are those vessels allowed to fish within the 12 nautical mile limit north of Barra Head.

Scientific background

Historical perception of herring stocks spawning to the west of the British Isles.

The definition of herring stocks to the west of the British Isles has changed considerably over the last five decades. Parrish and Saville (1965) considered the herring stocks to the west of the British Isles to consist of two main components, the ‘oceanic’ and ‘shelf’ populations. The oceanic populations consisted of a Scottish west coast winter/spring spawning stock and a southern Irish winter/spring spawning stock. The boundary between these two stocks was considered to be the central to southern west coast of Ireland. The other boundary was in the Irish Sea.

Parrish and Saville (1965) illustrated two major groups of shelf spawners, the Scottish west coast Minch stock and Irish Sea stock. The principal North Sea stock(s) were also illustrated along with interchange between west of Scotland and North Sea distributions. In the paper they divided the shelf spawners into northern Irish Sea, southern Irish Sea (Dunmore autumn/winter spawners), Clyde winter-spring spawners and Minch summer-autumn spawners. They also pointed out the high similarity between Irish Sea and Minch herring.

In subsequent years, further spawning locations were recorded so that at present the following are still considered the main spawning components: Irish Sea (combined Manx and Mourne), Celtic Sea (Dunmore East), south-west Ireland (Baltimore, Kerry and Galway), northwest Ireland (Donegal), Firth of Clyde and Scottish west coast (Minch). The HAWG (ICES 1979) carried out correlation analyses on age composition data to determine possible associations between fish from several of these spawning components. They concluded that the south Minch and the northwest of Ireland were areas in which a complex stock mixing took place. King (1985) examined a number of morphometric characteristics of fish from nine of the west coast spawning grounds and proposed a number of associations. Using this method, the Irish Sea components (Manx and Mourne) were shown to be closely related with a certain degree of intermingling. The association between the Clyde stock and both the Manx and Minch stocks indicated that the autumn spawners present in the Clyde could migrate out of the Clyde to spawn in these regions (also suggested by Morrison and Bruce (1981) on the basis of tagging experiments). There was a clear separation of the Dunmore East stock from the three stocks on the west coast of Ireland. The later stocks (west Cork, Kerry and Galway) were shown to be closely related suggesting they could be considered as one cohesive unit. This is in agreement with the findings of Grainger (1976). The similarities in morphological characteristics of Donegal and Minch stocks could be due to mixing of the autumn and spring spawners which are difficult to separate, rather than a close affinity of the two stocks.

In summary, Parrish and Saville (1965), HAWG (1979) and King (1985) suggested an interlinking of herring in areas VIa and VIIaN, and the Celtic Sea appearing as a separate group. The status of the west coast of Ireland populations appeared unclear. However, it did appear that boundaries between putative stocks probably occurred on the west coast of Ireland and toward the southern Irish Sea.

Perception of herring stocks spawning to the west of the British Isles from WESTHER results.

Previously, herring stock ID projects have generally been carried out using individual techniques, not always on spawning fish, to determine the stock structure of herring caught in different areas. WESTHER’s holistic approach, using a number of different techniques on the same individuals, has allowed apparent discrepancies implied by individual methods to be resolved and improve confidence in the results of stock

identification. It is through combining a suite of complementary identification techniques, covering multiple aspects and stages of herring life history and biology, that the strongest inferences on stock structure may be drawn. Morphometric and meristic differences (workpackages (WPs) 02.1, 02.2, 02.3), in a short-term study such as WESTHER, provide an indirect basis for stock structure. Parasite investigations (WP03) provide biological 'tags' to identify population components and migration between them. Genetics (WP04) and otolith microchemistry (WP06) provide the basic link to spawning site. Otolith microstructure (WP05) enables the timing of spawning to be elucidated. This is of especial importance in those areas where there is mixing of spring, autumn or winter spawners. The combined use of these methods (WP07) over the three years of the project, targeting sampling at both adults and juveniles, allowed the links from the various spawning grounds, through juvenile development on various nursery and overwintering grounds, to subsequent spawning stock affiliation to be described.

The **null hypothesis** is that there is only one herring population to the west of the British Isles, with no detectable differences between any of the geographically and temporally separated spawning components. Three alternative hypotheses can then be postulated, for the spawning (S) components, juveniles (J) and feeding (M) aggregations respectively, to be tested from data produced in the different workpackages, and it is these that inform this section.

Alternative hypothesis 1: the different spawning aggregations sampled are discrete at spawning time and are, therefore, separate components.

Alternative hypothesis 2: there is clear distinction of juveniles sampled on different nursery grounds.

Alternative hypothesis 3: fish from each spawning aggregation remain discrete on their feeding grounds.

Alternative hypothesis 1 - the different spawning aggregations sampled are discrete at spawning time and are, therefore, separate components.

Classification success of spawners for WPs 02.1, 02.2, 06 and 07 (see below for descriptions) is generally high suggesting that there is strong evidence to reject the null hypothesis because the different spawning aggregations sampled are discrete at spawning time. We accept that we have not sampled all spawner sites across the area and that our samples may not be representative of all spawning types in each management unit (proven by spawners caught and analysed in the VIaS and VIIb,c M sample (what should have been a sample of non-spawning adults) being different to S sample spawners caught and analysed from the same area; also we know there are winter spawners in VIa North that were unable to be sampled).

WP02.1 – Body Morphometry.

Classification from discriminant analysis of the aggregated temporal pairs of samples of spawning herring (Table 1) gives a success rate of between 72.5 and 96.1% - a very high success rate, providing strong evidence that the different spawning aggregations sampled are indeed discrete at spawning time.

Table 1. WP02.1 – Body Morphometry. Classification (in percent) from Discriminant Analysis of the aggregated temporal pairs of samples of spawning herring. The "X" sample is the Baltic spring spawning herring outgroup.

Pair	*S-06A*	*S10B*	*X01A*	*S04A*	*S10A*	n
Irish Sea (S06A)	**79.5**	6.0	2.0	9.5	3.0	200
Cape Wrath (S10B)	2.0	**84.3**	0.0	8.6	5.1	198
Western Baltic (X01A)	0.0	0.5	**96.1**	1.0	2.4	206
Donegal (S04A)	9.7	8.7	3.4	**72.5**	5.8	207
Isle of Skye (S10A)	4.3	8.7	5.8	8.0	**73.2**	138

WP02.1 – Otolith Shape Morphometry.

Classification from discriminant analysis of the aggregated temporal pairs of samples of spawning herring (Table 2) gives a success rate of between 64.2 and 93.4% - again a very high success rate, providing strong evidence that the different spawning aggregations sampled are indeed discrete at spawning time.

Table 2. WP02.1 – Otolith Shape Morphometry. Classification (in percent) from Discriminant Analysis of the aggregated temporal pairs of samples of spawning herring.

pair	*S-06A*	*S10B*	*X01A*	*S04A*	*S10A*	*n*
Irish Sea (S06A)	**78.3**	7.9	1.6	10.6	1.6	189
Cape Wrath (S10B)	9.3	**73.8**	1.1	10.4	5.5	183
Western Baltic (X01A)	2.0	0.0	**93.4**	4.1	0.5	197
Donegal (S04A)	6.1	10.5	2.2	**66.9**	14.4	181
Isle of Skye (S10A)	2.4	7.3	1.6	24.4	**64.2**	123

WP03 – Parasites as biological tags.

Figure 2 illustrates the percentage prevalence of the different parasite tags in the spawning samples. There were significant differences in infection between the Celtic Sea (S01), Dingle (S02), Irish Sea (S06) and Clyde (S05) spawners. This suggests that these spawning adults have retained the different early infection characteristics that can only have been picked up in different nursery areas. The significant differences between the adults therefore suggest that they are all separate stock components. The Rosamhil (S03) and Donegal (S04) samples were much closer, suggesting a possible connection, although similar levels of infection do not necessarily mean that they belong to the same stock. There were also significant differences in infection between the Cape Wrath (S10B) and Skye (S10A) samples suggesting that they represent different stock components. The Cape Wrath spawners shared parasite characteristics with juveniles sampled in the North Sea suggesting that they spent some of their life history there; the two Skye samples were quite distinct from each other. The resulting suggestions for spawners from this individual workpackage are:

i. Celtic Sea, Dingle, Irish Sea, Clyde and Cape Wrath spawners are all separate components.

ii. Donegal and Rosamhil spawners belong to the same stock component.

iii. The two samples from different, but geographically close positions near the Isle of Skye, in different years, represent different components.

WP04 – Genetic characterisation of herring stocks.

Analysis of pairwise FSTs among spawning samples reveals that almost all significant differences involve the Rügen (western Baltic) samples. The western Baltic samples were taken to provide an outgroup against which to compare the WESTHER samples. Since differences in FST are hard to visualise as a raw data matrix we summarised these data as multidimensional scale (MDS) plot (see Figure 3). Again, the emerging picture was that the western Baltic samples were very different from all other samples (but not from each other). The Canadian samples (a second outgroup sample used for the genetics WP only) also showed differences from Dingle and Rosamhil in 2004, but generally were not genetically different from the other WESTHER area samples. While there was a significant difference between two of the WESTHER herring samples (Skye and Rosamhil in 2004) the overall picture was one of weak levels of genetic differentiation among the western spawning samples.

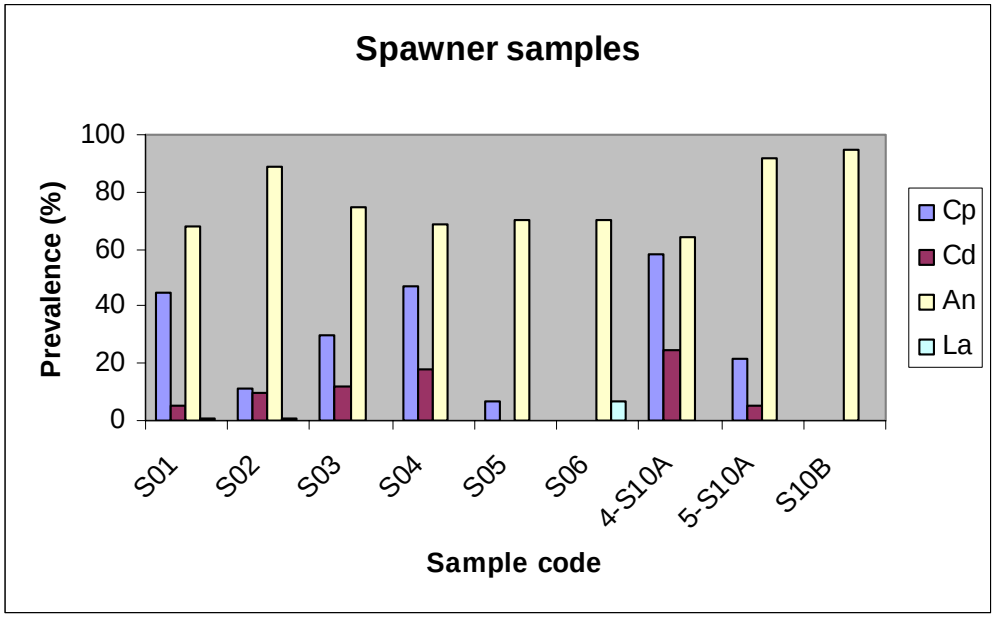


Figure 2. WP03 – Parasites as biological tags. Prevalence of four parasite tags in samples of spawning herring from the different localities sampled. Cp: *Cercaria pythionike*; Cd: *Cercaria doricha*; An: *Anisakis simplex sensu stricto*; La: *Lacistorhynchus tenuis.*

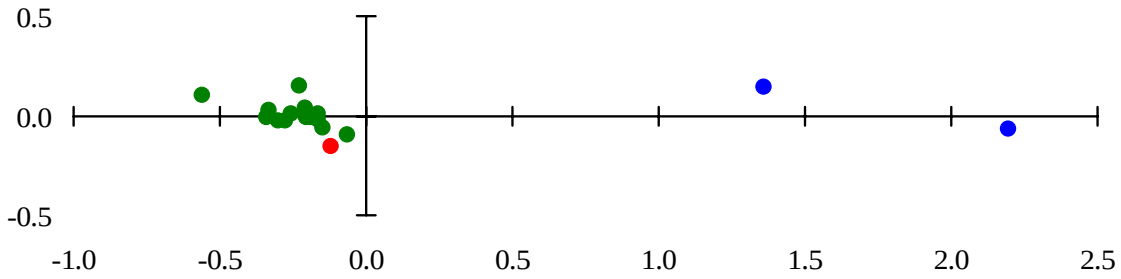
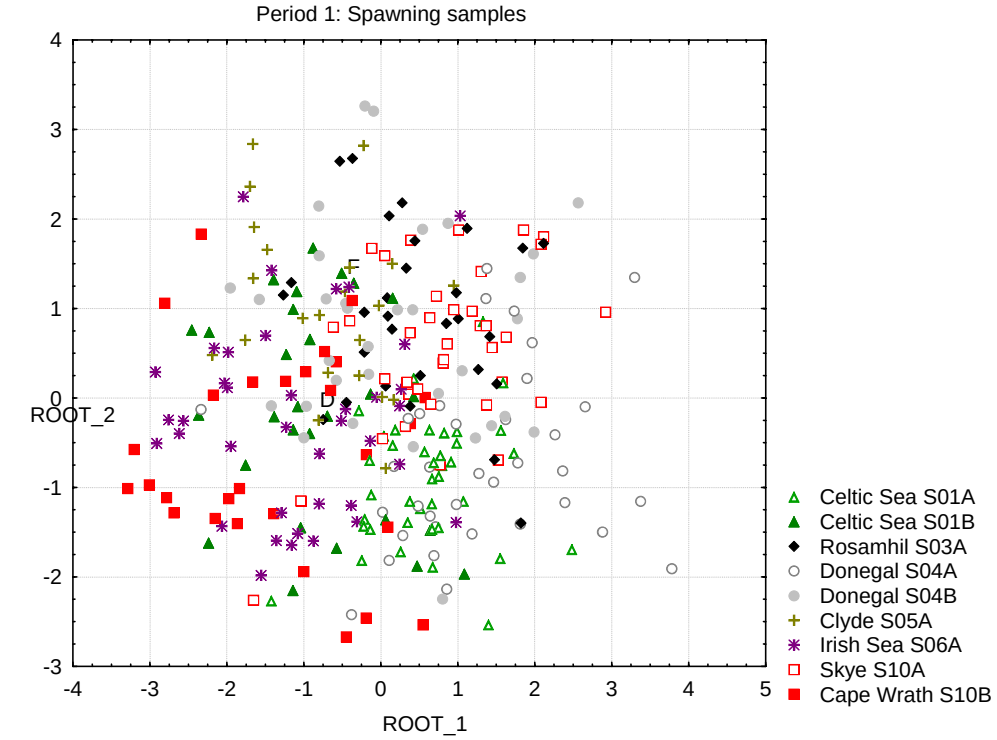


Figure 3. WP04 – Genetic characterisation of herring stocks. Multidimensional scale (MDS) plot of levels of pairwise genetic differentiation (F_{ST}) among western herring spawning samples (green circles) and outliers from the Baltic Sea (blue circles) and Hudson Canyon, western Atlantic (red circle).

WP06 – Otolith Core Microchemistry.

The correct classification of spawning samples to known source was lower than for the two morphometry workpackages. However, classification rates of up to 87% were possible with this technique (see Figure 4 and Table 3) and lower values may be indicative of juvenile mixing (see alternative hypothesis 2) in different nursery grounds prior to spawning, or of juvenile stages being exposed to similar water chemistry characteristics ("oceanic" versus "neritic/coastal" environmental conditions).



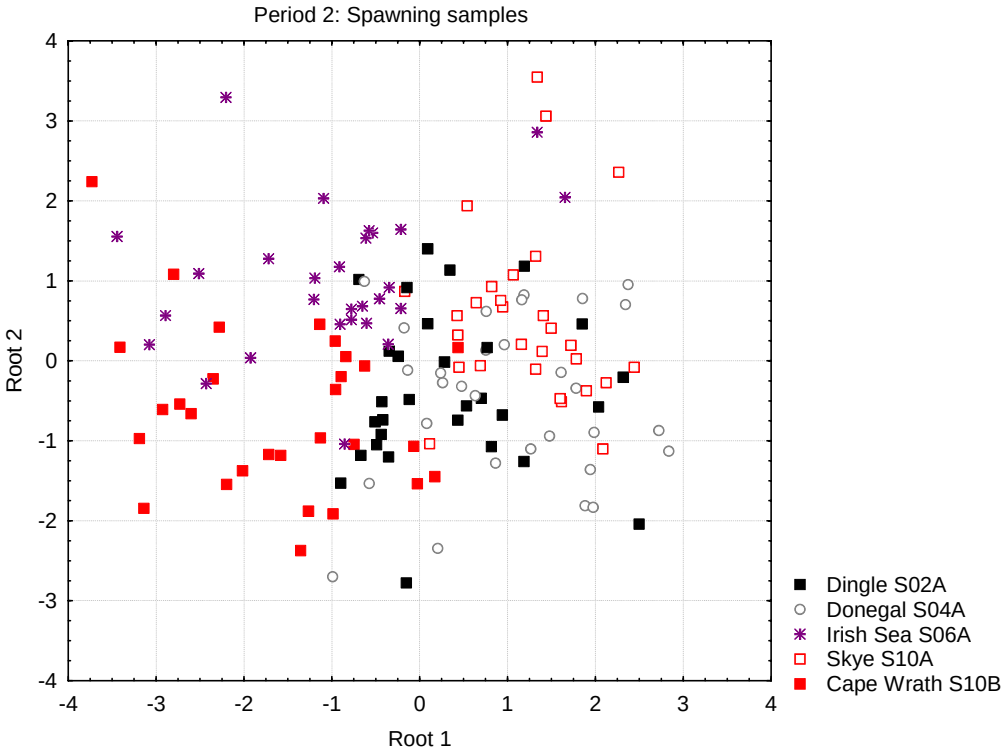


Figure 4: WP06 – Otolith Core Microchemistry. Separation of fish from spawning samples in period 1 – autumn 2003 to spring 2004 (a) and period 2 – autumn 2004 to spring 2005 (b) based on first two canonical axes calculated by discriminant analysis of log-transformed otolith chemical concentrations. The first axis is mostly associated with Strontium and Manganese concentrations

Table 3. WP06 – Otolith Core Microchemistry. Temporal Analysis - Characterisation of spawning group samples by discriminant analysis. Correct classification of samples to known source, based on otolith composition (data log-transformed), Period 1 (autumn 2003 to spring 2004).

Source Rows = Observed	Percent Correct Classification	S01A	S01B	S03A	S04A	S04B	S05A	S06A	S10A	S10B	Total N
S01A	87.2	87.2	0.0	0.0	2.6	0.0	2.6	2.6	2.6	2.6	39
S01B	17.9	10.7	17.9	3.6	3.6	3.6	17.9	21.4	7.1	14.3	28
S03A	48.3	6.9	6.9	48.3	10.3	3.4	10.3	0.0	13.8	0.0	29
S04A	38.9	33.3	0.0	0.0	38.9	2.8	0.0	2.8	19.4	2.8	36
S04B	15.2	9.1	3.0	12.1	12.1	15.2	15.2	6.1	18.2	9.1	33
S05A	72.7	4.5	0.0	4.5	0.0	13.6	72.7	4.5	0.0	0.0	22
S06A	52.6	15.8	5.3	2.6	0.0	5.3	7.9	52.6	0.0	10.5	38
S10A	48.6	8.1	0.0	13.5	5.4	16.2	2.7	0.0	48.6	5.4	37
S10B	53.6	3.6	7.1	0.0	3.6	3.6	3.6	21.4	3.6	53.6	28

WP07 – Multivariate statistical analysis of combined techniques.

Using the combination of data from body and otolith shape morphometry, parasites as biological tags and otolith core microchemistry, the correct classification of spawning samples to known source was mostly greater than 70%. When the spawning samples from each year were aggregated to site the classification rate fell for only one of the spawning samples and was otherwise > 77% (Table 4).

Table 4. WP07 – Multivariate statistical analysis of combined techniques. Classification scores from discriminant analysis based on multivariate statistical analysis of data from four WESTHER workpackages.

	S01	S02	S03+S04	S06	S10A	S10B
Dunmore East **(S01)**	**81.4**	1.7	5.1	10.2	1.7	0
Dingle **(S02)**	9.1	**54.5**	18.2	13.6	4.5	0
Rosamhil + Donegal **(S03+S04)**	7.7	1.9	**80.8**	3.8	3.8	1.9
Irish Sea **(S06)**	11.5	0	6.6	**77.0**	1.6	3.3
Skye **(S10A)**	0	1.7	3.4	1.7	**89.8**	3.4
Cape Wrath **(S10B)**	4.2	2.1	6.2	0	0	**87.5**

These scores again showed a high classification success rate, providing strong evidence that the different spawning aggregations sampled are indeed discrete at spawning time.

Alternative hypothesis 2 – there is clear distinction of juveniles sampled in different nursery grounds.

The WPs on parasites and otolith microchemistry act as tags for the juvenile stages of herring and therefore provide the best place to search for evidence of juvenile separation. There is a clear distinction of many of the different juvenile samples, based on these two most informative WPs. There is, however, strong evidence from both of these WPs that juveniles from separate spawning areas mix in some of the nursery areas sampled. Again we did not sample all of the nursery grounds throughout the area (as evidenced by the presence of juveniles mostly spawned in the spring, even though several of our spawning samples were autumn spawners) but with the information we have we can ***distinguish the origin*** of juveniles even in mixtures, and thus we can accept the alternative hypothesis 2.

WP03 – Parasites as biological tags.

There was little variation of parasite prevalence within most sampling areas, but the greatest variation of all four parasites was apparent in the Irish Sea west (J04) samples. The wide scatter of sampling positions within this area probably accounted for much of this variation. *A. simplex* is much more common in the more offshore sites of

the Minch (J06) and Stanton Bank (J07); *C. pythionike* and *C. doricha* have significantly higher prevalences in the Scottish sea lochs (J05) than elsewhere, and *L. tenuis* only infected juvenile herring in the Irish Sea sampling sites J03 and J04. Levels of *Anisakis* infection in the two Minch (J06) samples were significantly different. These samples were taken from positions scattered over a very wide area. Levels of infection with both *Cercaria* spp. were significantly different in the two Stanton Bank (J07) samples (Figure 5).

Comparing these samples to the spawning adults enables an assessment of any mixing of juveniles from different spawning components in the nursery areas to be made, and the data suggest the following:

i. Stanton Bank (J07) is a nursery ground where juveniles originating from spawning grounds from the north-west of Ireland and western Scotland mix.

ii. the Irish Sea contains juveniles (J03 and J04) arising from spawning in both the Irish Sea and the Celtic Sea.

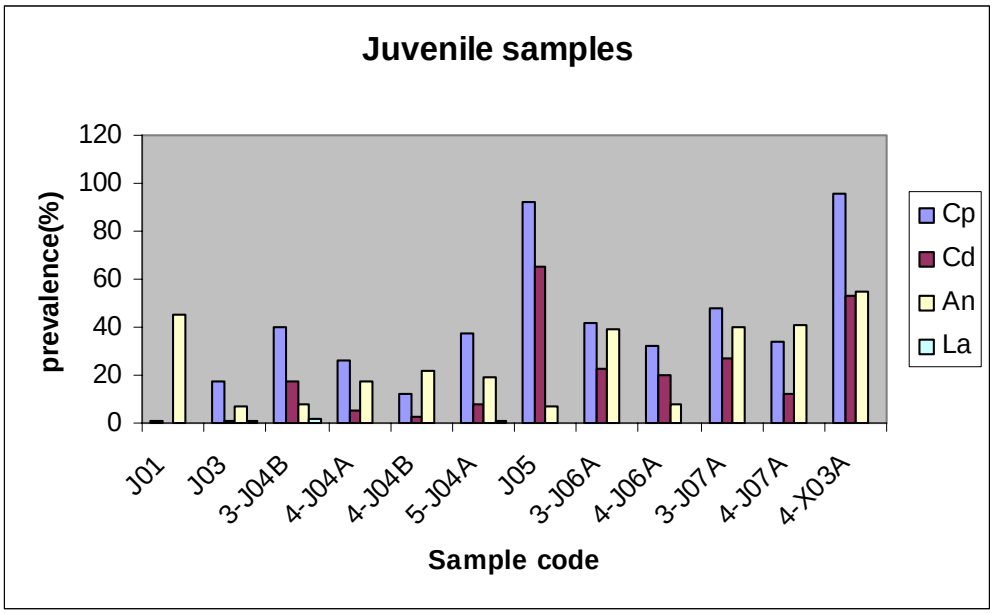


Figure 5. WP03 – Parasites as biological tags. Prevalence of four parasite tags in samples of juvenile herring from the different localities sampled. Cp: *Cercaria pythionike*; Cd: *Cercaria doricha*; An: *Anisakis simplex sensu stricto*; La: *Lacistorhynchus tenuis.*

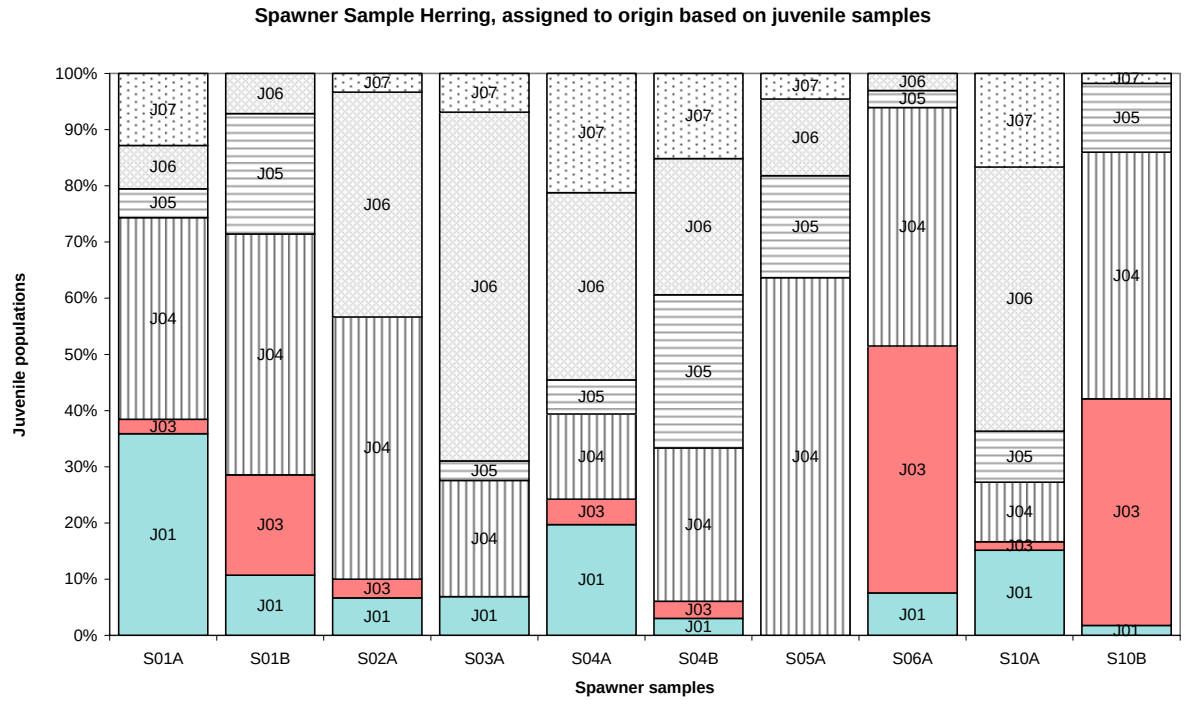
WP06 – Otolith Core Microchemistry.

Figure 6 illustrates a similar picture to the parasite data suggesting:

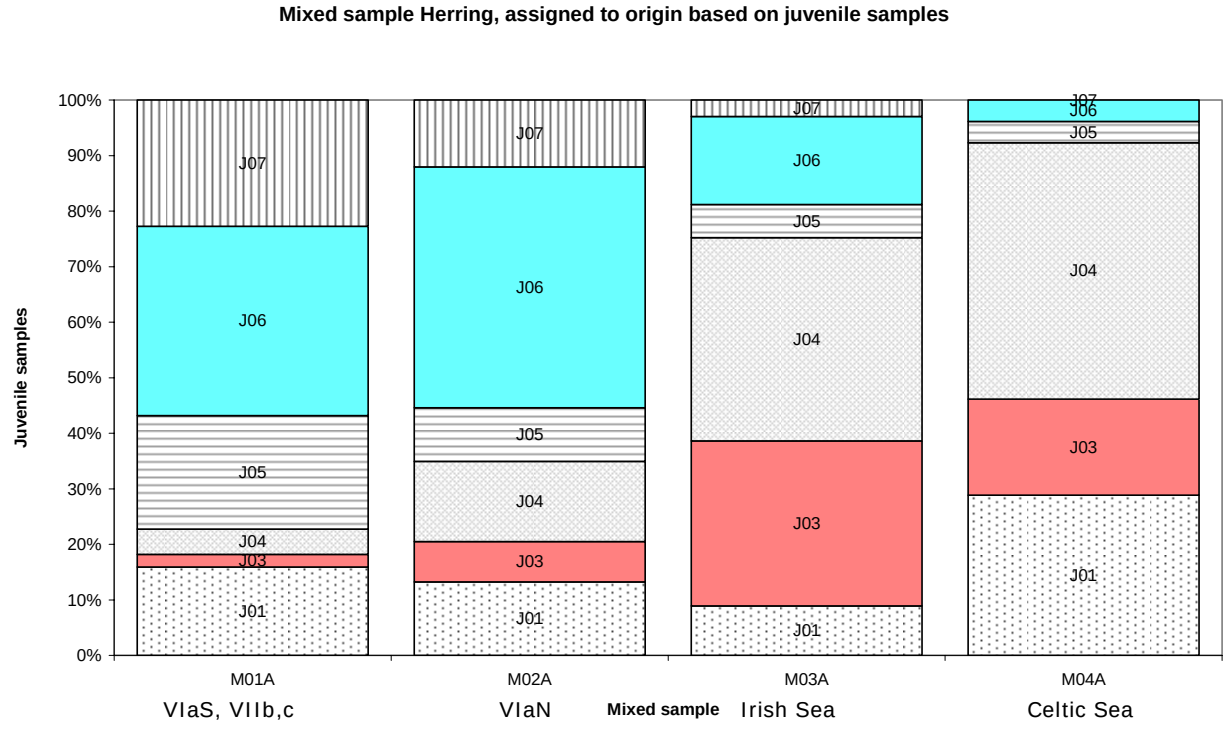
i. the Irish Sea contains a mixture of juveniles spawned in the Irish Sea, the Celtic Sea and probably the Clyde too.

ii. Stanton Bank and the Minches likely act as nursery areas for fish spawned to the northwest of Ireland and around Skye (western Scotland).

iii. there is a lesser signal of mixing of juveniles in the Scottish west coast sea lochs of fish spawned in the Clyde, and both spawning samples off the Scottish coast (Skye and Cape Wrath).



(a)



(b)

Figure 6. WP06 – Otolith Core Microchemistry. Assignment of adult herring in (S) spawning (a) and (M) mixed (b) group samples to (J) juvenile population of origin. The classification model was built with discriminant analysis using the log-transformed otolith core concentrations for the juvenile samples, combining A and B samples, and across years.

Alternative hypothesis 3: fish from each spawning aggregation remain discrete on their feeding grounds

We reject alternative hypothesis 3 because there is evidence to suggest mixing of adults from separate spawning components, especially in VIa North. There is evidence to suggest that the Celtic Sea and VIIj spawning ground fish do not mix with the more northerly spawners to the same extent that the more northerly spawners mix with each other. The science, therefore, suggests links between the areas, with fish spawning in different areas mixing, to varying extents, on feeding grounds.

For each workpackage it is difficult to assess the level of mixing of non-spawning adults from the putative mixed sample taken from VIaS and VIIb,c (M01) as the majority of those fish were spawning adults thus not informative to the process.

We do not consider WP02.2 on otolith shape morphometry to be informative enough to enable conclusions to be drawn on the level of mixing in different feeding grounds.

WP02.1 – Body Morphometry.

Fish sampled in VIa North (M02) showed a mixture of fish from all spawning samples analysed. Fish with VIa North and VIaS and VIIb,c body types were dominant, with fish with body types from the Irish Sea and Celtic Sea and VIIj also present (see Tables 5 to 8). Fish sampled in the Irish Sea (M03) showed a mixture of morphologies. Given that juveniles here appear to originate from different spawning areas and adults probably spend much of their time on the continental shelf to the west of Scotland and northwest of Ireland (the Malin Shelf) feeding this is not unexpected. The Irish Sea "type" is present in every level of statistical analysis, however. The results for the Celtic Sea and VIIj samples (M04) are unclear from this workpackage. Generally, the "best" classified spawner samples were from VIa North and VIaS and VIIb,c so were dominant in any level of analysis. At the most aggregated levels (Tables 6 to 8), two variable body types within VIa North (the Skye and Cape Wrath spawners) were combined and this then produced the potential for high misclassification.

Table 5. WP02.1 – Body Morphometry. Results of the classification run of mixed adults (with corresponding management area) to spawners per sampling site. 'samples' gives the number of mixed samples aggregated. 'n' gives the number of fish classified.

	S01 Celtic Sea	*S02 Dingle*	*S03/04 Donegal/Rosamhil*	*S05 Clyde*	*S06 Irish Sea*	*S10A Skye*	*S10B Cape Wrath*	*samples*	*n*
M01 (VIaS and VIIb,c)	0.16	0.08	0.14	0.08	0.12	0.30	0.12	1	161
M02 (VIa North)	0.16	0.08	0.18	0.04	0.16	0.17	0.21	2	920
M03 (Irish Sea)	0.17	0.07	0.13	0.08	0.15	0.29	0.11	3	428
M04 (Celtic Sea and VIIj)	0.09	0.08	0.51	0.01	0.11	0.04	0.17	2	850

Table 6. WP02.1 – Body Morphometry. Results of the classification run of mixed adults per sample to spawners (aggregated to management area) for Period 1 (autumn 2003 to spring 2004). 'n' gives the number of fish classified.

	VIaS and VIIb,c	*VIa North*	*Irish Sea*	*Celtic Sea and VIIj*	n
3-M02A	0.52	0.20	0.08	0.20	475
3-M03A	0.36	0.17	0.17	0.30	120
3-M04A	0.18	0.53	0.07	0.22	350

Table 7. WP02.1 – Body Morphometry. Results of the classification run of mixed adults per sample to spawners (aggregated to management area) for Period 2 (autumn 2004 to spring 2005). 'n' gives the number of fish classified.

	VIaS and VIIb,c	*VIa North*	*Irish Sea*	*Celtic Sea and VIIj*	*n*
4-M01A	0.43	0.20	0.21	0.17	161
4-M02A	0.37	0.20	0.20	0.22	445
4-M03A	0.30	0.26	0.28	0.16	153
4-M04A	0.25	0.24	0.33	0.18	500
5-M03A	0.46	0.18	0.25	0.10	155

Table 8. WP02.1 – Body Morphometry. Results of the classification run of mixed adults (with corresponding management area) to spawners aggregated to management area. 'samples' gives the number of mixed samples aggregated. 'n' gives the number of fish classified.

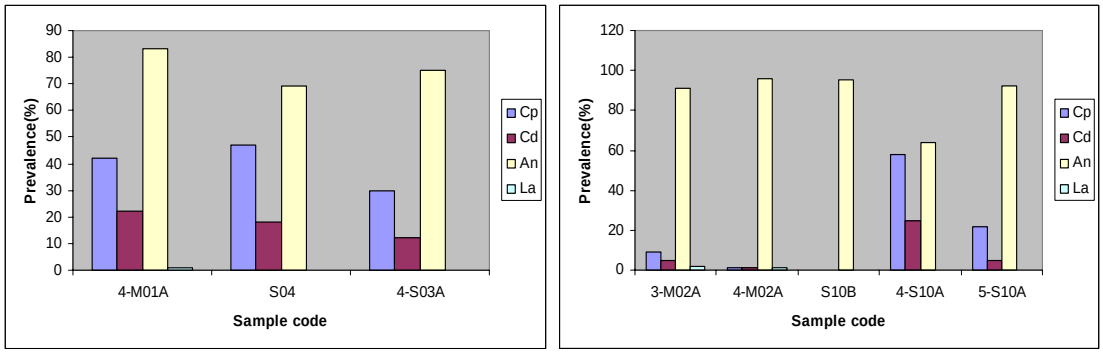
Management area	*VIaS and VIIb,c*	*VIa North*	*Irish Sea*	*Celtic Sea and VIIj*	*samples*	*n*
M01 (VIaS and VIIb,c)	0.40	0.18	0.16	0.27	1	161
M02 (VIa North)	0.43	0.18	0.15	0.24	2	920
M03 (Irish Sea)	0.37	0.18	0.19	0.27	3	428
M04 (Celtic Sea and VIIj)	0.19	0.57	0.11	0.14	2	850

WP03 – Parasites as biological tags.

The VIaS and VIIb,c sample (M01) was very similar to the Rosamhil (S03) and Donegal (S04) spawners (Figure 7). The occurrence of fish infected with *L. tenuis* suggested a component of recruits from either the Irish Sea or the eastern North Sea (both well documented areas for this parasite, e.g., MacKenzie, 1987). Samples from VIa North (M02) were very similar to Cape Wrath spawners (S10B), but the occurrence of some fish infected with *C. pythionike* and *C. doricha* indicated a component of Skye spawners (S10A) or possibly from Donegal (S04). Again, the occurrence of fish infected with *L. tenuis* suggested a component of recruits from either the Irish Sea or the eastern North Sea. Potentially then, fish originating from spawning grounds in VIa North, in VIaS and VIIb,c and the Irish Sea could all be mixing over the Malin Shelf (see Figure 8). The Irish Sea samples (M03) were closest to Irish Sea spawners, but with a small component infected with *C. pythionike* and *C. doricha*, possibly Celtic Sea spawners (S01). The Celtic Sea and VIIj sample (M04) was closest to the Dingle Bay spawners (4-S02A), but with slightly lower levels of infection with all the tag parasites. The absence of *L. tenuis* indicated that no component of Irish Sea spawners could be detected with this method in the Celtic Sea and VIIj.

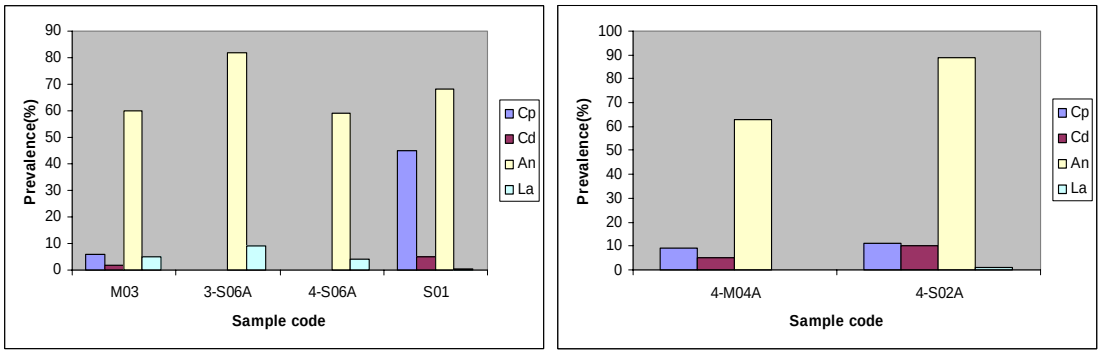
WP04 – Genetic characterisation of herring stocks.

Mixed Stock Analysis software was used to assess the spawning contributions to the adult fishery aggregations. Table 9 shows the raw data output. The conclusion was that some combination of (i) weak genetic differentiation among spawning groups and (ii) an absence of known spawners to the west of Scotland (and also likely herring from the North Sea) contributed to the significant proportion of 'unknown' fish (ca. 40%) in each sample during this analysis. However, it is apparent that one sample (S04) seemed to contribute to all of the mixed stocks. This was deemed unlikely for certain distant areas. Thus it is possible that there is a bias towards this sample (and also S10) because they are the largest baseline contributors.



M01 sample –VIaS and VIIb,c

M02 sample – VIa North



M03 sample – Irish Sea

M04 sample – Celtic Sea and VIIj

Figure 7. WP03 – Parasites as biological tags. Relationships of mixed aggregations to spawner samples. Cp: *Cercaria pythionike*; Cd: *Cercaria doricha*; An: *Anisakis simplex sensu stricto*; La: *Lacistorhynchus tenuis*.

Table 9. WP04 – Genetic characterisation of herring stocks. 2003-5, genetic stock identification (8 loci); proportions of adult feeding herring assigned to spawning stocks in the WESTHER area using all temporal samples combined.

		Estimate	SE	CV	Score			Estimate	SE	CV	Score
M01	S01A				-32.00	M03	S01A	0.019	0.003	0.14	-1.30
	S01B	0.066	0.023	0.34	-0.10		S01B	0.091	0.023	0.25	0.30
	S02A	0.141	0.027	0.19	-0.10		S02A	0.023	0.003	0.12	-0.60
	S03A	0.028	0.012	0.45	-0.40		S03A	0.042	0.012	0.28	-0.40
	S04A	**0.231**	**0.031**	**0.13**	**0.00**		**S04A**	**0.314**	**0.028**	**0.09**	**0.00**
	S04B	0.109	0.025	0.23	0.20		S04B	0.151	0.021	0.14	-0.20
	S05A	0.044	0.015	0.33	0.00		S05A				0.10
	S06A	0.149	0.020	0.14	-0.10		S06A	0.238	0.025	0.10	0.40
	S10A	0.060	0.019	0.31	0.30		S10A	0.033	0.009	0.28	-0.80
	S10B	0.167	0.028	0.17	0.00		S10B	0.084	0.011	0.13	0.20
	Unknown	0.006					Unknown	0.004			
M02	S01A	0.008	0.001	0.08	-14.20	M04	S01A	0.032	0.007	0.21	-0.50
	S01B	0.033	0.005	0.15	-1.60		S01B	0.085	0.014	0.17	0.10
	S02A	0.009	0.001	0.10	0.20		S02A	0.048	0.007	0.14	-0.40
	S03A	0.018	0.004	0.20	0.10		S03A	0.006	0.003	0.46	-0.60
	S04A	**0.258**	**0.013**	**0.05**	**0.20**		**S04A**	**0.265**	**0.020**	**0.08**	**0.00**
	S04B	0.152	0.010	0.07	0.30		S04B	0.067	0.008	0.12	0.00
	S05A	0.010	0.003	0.30	-1.00		S05A	0.067	0.010	0.15	0.00
	S06A	0.178	0.010	0.06	0.30		S06A	0.179	0.014	0.08	-0.10
	S10A	0.092	0.009	0.10	0.10		S10A	0.041	0.005	0.13	-0.20
	S10B	0.234	0.012	0.05	0.00		S10B	0.202	0.017	0.09	0.30
	Unknown	0.007					Unknown	0.009			

WP06 – Otolith Core Microchemistry.

VIa North (M02) contained fish with juvenile signatures from the Irish Sea, Scottish sea lochs, Minches and Stanton Bank, suggesting contributions of fish spawning in VIa North, in VIaS and VIIb,c and the Irish Sea. 70% of the herring sampled in the Irish Sea (M03) had an Irish Sea juvenile signature – predominantly Irish Sea spawners. The Celtic Sea and VIIj samples (M04) showed a mix of fish that had spent their juvenile period in both the Irish Sea and the Celtic Sea and VIIj and this concurred with what is known about the spawners. It seems likely then that the Irish Sea and Celtic Sea and VIIj were less mixed from the viewpoint of spawners than the other more northerly areas.

WP07 – Multivariate statistical analysis of combined techniques.

Evidence from WP07 is that some of the putative mixtures sampled contained mixtures of fish from different spawning aggregations. The results from this WP are probably less informative than from the other WPs because so few of the M fish sampled were available with data from each of the techniques in common. Thus the statistics are at the limit of their ability to discriminate. Generally, at each level of analysis the dominant contributors to fish sampled in VIaS and VIIb,c (M01) and VIa North (M02) were fish spawned in VIa North, with lesser contributions from VIaS and VIIb,c and possibly even the Irish Sea, in both areas. There was a Celtic Sea and VIIj contribution in these areas, however, the two Celtic Sea spawner samples had by far the lowest classification success and were unstable (i.e., their presence was less reliable than for the other spawner groups). The Irish Sea (M03) samples were dominated by fish spawned in the Irish Sea. However, the Celtic Sea and VIIj (M04) samples showed a proportion of fish from the Irish Sea (likely the influence of a juvenile period spent in the Irish Sea) as well as a proportion of fish spawned in VIaS and VIIb,c. This last result may be the influence of two factors; (i) misclassification of fish from the Celtic Sea and VIIj as VIaS and VIIb,c spawners (and instability of those Celtic Sea and VIIj spawners where the highest proportion of VIaS and VIIb,c fish are seen), (ii) the influence of the body morphometry component of the multivariate analysis which, on its own, was unable to provide a clear discrimination of the M04 sample.

Implications for stock assessment

Biologically, a fish stock can be identified as a population or part of a population of a given species that lives in a particular geographical area, usually with a particular migration pattern, specific spawning grounds, and subject to a distinct fishery (e.g., Waldman 2005b). For practical purposes, biological and management stock units sometimes diverge. Management units, however, do not necessarily reflect meaningful biological entities or the spatial heterogeneity of fish distributions. From a scientific perspective, we have to consider the biological units.

Two of the basic assumptions of stock assessment are that (1) the stock is a closed unit, and (2) the data used in assessments are representative of the entire stock. The first assumption implies that stock gain is only through birth, not immigration, and loss from the stock is through mortality, not emigration. The second assumption implies that catches are not removed from certain components only, but fishing mortality is distributed homogenously over the entire stock. Data from surveys should also be a relative measure of the entire stock and its geographical distribution.

The current assessment of herring to the west of the British Isles assumes separate stocks in the following ICES areas, i.e., VIa North, VIaS and VIIbc, Irish Sea, and Celtic Sea and VIIj. The results from WESTHER suggest that under the current stock assessment units (ICES, 2007), both the basic assumptions above are violated. Violating the assumption of a closed stock unit for stock assessment will be less problematic if the catch and survey input data are only from spawning aggregations and the fisheries only exploit spawning aggregations. With the level of mixing indicated by WESTHER this, however, is not the case. For example, data for the assessment of VIa North herring are from both the summer acoustic survey and commercial fishery which target feeding aggregations that are suggested to be a mixture of fish originated from several spawning

sites outside VIa North (i.e., adults from VIaS and VIIbc, Irish Sea and possibly even the Clyde).

The scientific results from WESTHER, as summarised in the previous section, have provided little evidence of discreet structuring of juvenile and adult herring west of the British Isles, outside of the spawning seasons. However, high classification success of spawning aggregations for WPs 02.1, 02.2, 06 and 07 provided evidence of population structuring by spawning time and spawning sites, indicating a high degree of natal fidelity. Evidence suggests significant migration and mixing of herring that originate from different spawning areas, especially to and from feeding grounds and by repeat spawners to spawning grounds (Figure 8). The degree of mixing of juvenile and first time spawners is more area specific, but still significant in some areas, e.g., mixing of Celtic and Irish Sea juveniles in the Irish Sea. Overall then, there appear to be strong links between the sampled areas, but it does not appear that there is a single population to the west of the British Isles. Thus we reject the null hypothesis set up above. We accept, however, that there is considerable mixing of spawning components in both the juvenile and adult phases. From an assessment perspective there might be benefits for the assessment to cover a larger area (i.e., combining some of the existing assessment areas), rather than trying to assess separate populations. This will have implications on current stock assessment practices and the alternatives are discussed below.

I - Single stock

The main implication of aggregating all input data into a single stock assessment is that the larger population units will drive the assessment and consequently the perception of stock status. Signals from the smaller spawning population units such as the Celtic and Irish Sea will be masked or lost.

Fishery independent implications

Assessing the west of British Isles herring as a single stock will have implications on the survey data requirements. Current surveys focus mostly on the biomass and structure of spawning aggregations, with the exception of the VIa North summer acoustic survey. Considering that the Malin Shelf area appears to be the main area of aggregation for feeding adults, this survey will provide the best indication of overall biomass and structure of the stock. The survey area will need to be extended to the south. Better survey coordination should be considered with the possible further extension of the summer survey into VIaS and VIIb,c by displacing current survey effort from the spawning biomass survey carried out in VIa South. Effort also needs to be maintained to monitor different spawning sites, either by acoustic or larval surveys. More survey effort is required on spawning sites in VIa North. Since the stoppage of the west coast larvae surveys the North Sea surveys switched from using LPE or LAI to MLAI (see ICES 2007). There is a possibility that a new technique such as this could be used in conjunction with the re-instatement of larvae surveys. Any new survey needs to be co-ordinated with the North Sea surveys since some VIa North larvae are advected eastward into the North Sea. Existing surveys on spawning grounds should be maintained. These surveys will continue to inform management in those areas, with the aim to protect the biodiversity of the spawning components. In terms of the stock assessment of the Malin Shelf, these surveys will be less informative, providing relative estimates for smaller population units. Priority should be given to a wider scale survey, covering most of the summer feeding distribution area on the Malin Shelf area where most of the mixing occurs. Survey effort should be diverted and coordinated to improve coverage on the Malin Shelf. Such a wider scale survey will provide a more reliable estimate of overall stock abundance of non-spawning adults mixing on the Malin Shelf for assessment purposes, as opposed to a number of smaller local surveys. The mixing of juveniles that is evident throughout the whole study area strongly suggests that no recruitment indices will be possible for each individual stock as currently defined.

Fishery dependent implications

The majority of the fisheries on herring to the west of the British Isles exploit spawning aggregations, with the clear exception of the fishery exploiting mixed feeding aggregations on the Malin Shelf. Catch data are currently collected from all fisheries, which should be maintained.

II - Two stocks: "Malin shelf" stock (VIa North, Clyde, VIaS and VIIb,c and Irish Sea) and "Celtic Sea" stock (VIIaS, VIIg, VIIh, VIIj and VIIk)

Brophy et al. (2006) investigated spawning season fidelity in sympatric populations of herring, concentrating on Celtic and Irish Sea populations. The study suggested that within the Irish Sea there is a large degree of mixing of juveniles from both the Irish and Celtic Sea, but very little mixing of the adult populations. Spawning populations between the two areas appear to be distinct in terms of the predominant spawning seasons, i.e., autumn spawners in the Irish Sea and winter spawners in the Celtic Sea. This supports the evidence from WESTHER suggesting that the Celtic Sea spawning-ground fish do not mix with the more northerly spawners (Figure 8) to the same extent as the more northerly spawners mix with each other. These results suggest the possible combination of current assessment areas into a northern, Malin Shelf, assessment (VIa North, Clyde, VIaS and VIIb,c and Irish Sea) and the retention of the current southern, Celtic Sea (VIIaS, VIIg, VIIh, VIIj and VIIk), stock assessment (Figure 9).

This combination of population units into a Malin Shelf stock assessment is analogous to the assessment of the North Sea stock (see, for example, ICES, 2007), which comprises a number of more or less well detectable population units (Mariani et al. 2005) that mix in the feeding areas (Ruzzante et al. 2006) and are targeted by multiple fleets across the entire area fished.

The general implications and implications specifically for fisheries dependent and independent input data for the assessment will be similar, although arguably less pronounced, to those discussed above for a single stock assessment approach.

Implications for management

The results of the EU-Project WESTHER suggest a significant amount of mixing of the currently defined three northern stocks (VIa North, VIaS and VIIb,c and Irish Sea) at various periods in their life history. The group therefore recommends merging these three stocks in the assessment, as discussed above, which would have implications for the collection of fishery dependent and fishery independent data. It is expected that any assessment of this area will be dominated by the dynamics of the VIa North component of the stock, the largest in terms of spawning stock biomass and abundance.

Assessing the herring to the west of the British Isles as two "stocks" does not suggest simply creating two management areas. There is a continued need to conserve the biodiversity of the western herring population components, as there are still numerous distinct spawning grounds in the area. Each of these spawning grounds is populated by a group of herring which, in general, have a certain level of site fidelity. The ability of the various analytical techniques used in WESTHER to identify and correctly classify individual fish to their spawning grounds suggests a reasonably high level of spawning site fidelity and hence population structure. The mosaic of spawning sites and their associated environmental conditions imparts an inherent diversity on the herring populations to the west of the British Isles. Maintenance of a wide range of spawning sites will help to maintain genetic and phenotypic diversity in the bigger combined Malin Shelf area, and thus the potential of herring across the whole area to adapt to a changing environment (Ruzzante et al. 2006).

To maintain the diversity it is necessary to ensure that single spawning populations are not targeted and fished to the level of extinction. Current theory suggests that if a population utilising a spawning ground is driven to extinction then with an increased level of the overall stock size the spawning ground will eventually be re-populated. However, the recovery time is variable and unpredictable. In addition the replacement population will not have the same (at least genetic) characteristics as the previous population.

For these reasons, ICES has recently advised in situations where a large management area is combining possibly separate population components/population units/spawning sites, that a sensible management should "prevent local depletion of any unit". This approach appears to be useful for the future management of the herring resource west of the British Isles. A fleet based management seems promising: most of the fleets operate in localised areas, so management could be undertaken at that local

level. In effect, this will result in spatially explicit management plans, primarily targeted at fleets, to ensure that all parts of the stock are exploited at a sustainable level.

Recommendations

The WESTHER group recommends to ICES and the management authorities to:

1. **Assess the herring to the west of the British Isles as two stock units** - Malin Shelf (including the current ICES stocks VIa North, VIaS and VIIb, c, Clyde and Irish Sea (VIIaN)) and Celtic Sea (the current Celtic Sea and VIIj stock). In the area studied in WESTHER we can hypothesise that there are two stock units within which data can be pooled for assessment. However, the boundary at the northern edge is unclear and there is no evidence presented in the report which separates autumn spawners in the north of Scotland west of 4°W from autumn spawning fish east of 4°W (the North Sea stock). The boundary is here for convenience.

2. Survey effort should be increased or diverted to a combined survey on non-spawner distributions mixing on the Malin Shelf.

3. The current monitoring of the spawning components should be maintained, but not to the detriment of a wider scale Malin Shelf survey. Spawning ground surveys might provide data on the dynamics of individual stock components, which are thought to be useful for the development of a fleet-based advice

However,

4. **Management plans should be fleet/area based,** aiming at preventing the local depletion of any population unit in the area, and should make adaptive changes if current fishing practices change, specifically the introduction of a new 1st or 2nd quarter fishery in the southern part of VIa North and/or northern part of VIaS and VIIb,c.

5. Management plans should recognise the importance of the populations in the north of area VIa as a potential source of herring to spawning grounds to the south.

6. Management plans should recognise that there are potentially two separate stock units on the west coast of the British Isles, these constitute a population in the Celtic Sea and VIIj and a metapopulation centred on area VIa.

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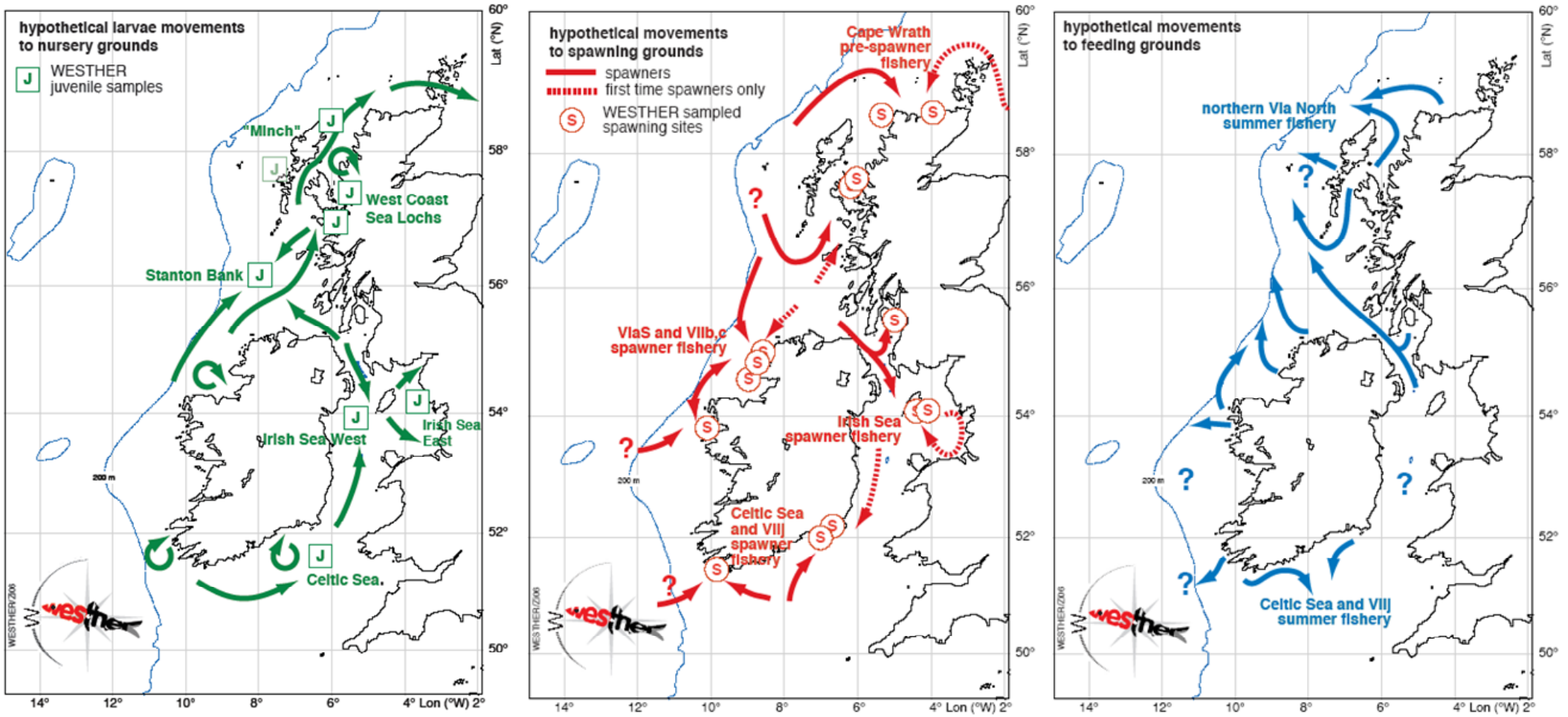

Figure 8. Hypothetical movements of juveniles and adults to feeding and spawning grounds based on historical evidence and WESTHER results.

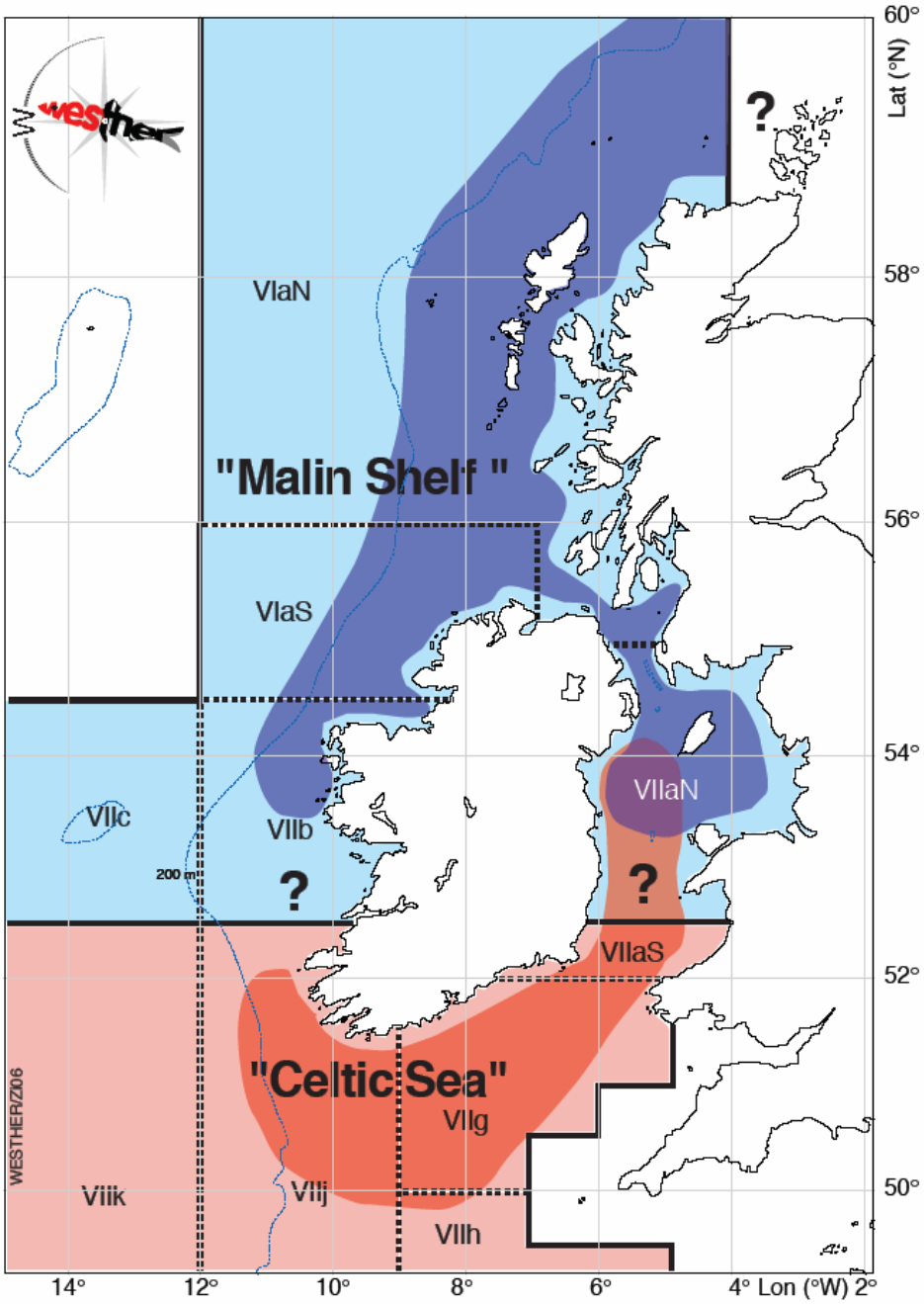

Figure 9. Proposed assessment units for assessments of western stocks, based on grouping suggested from WESTHER. Darker colours indicate known distribution of herring in those areas.