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Demersal fish biodiversity: species-level indicators and trends-based targets for the Marine Strategy Framework Directive

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The maintenance of biodiversity is a fundamental theme of the Marine Strategy Framework Directive. Appropriate indicators to monitor change in biodiversity, along with associated targets representing "good environmental status" (GES), are required to be in place by July 2012. A method for selecting species-specific metrics to fulfil various specified indicator roles is proposed for demersal fish communities. Available data frequently do not extend far enough back in time to allow GES to be defined empirically. In such situations, trends-based targets offer a pragmatic solution. A method is proposed for setting indicator-level targets for the number of species-specific metrics required to meet their trends-based metric-level targets. This is based on demonstrating significant departures from the binomial distribution. The procedure is trialled using North Sea demersal fish survey data. Although fisheries management in the North Sea has improved in recent decades, management goals to stop further decline in biodiversity, and to initiate recovery, are yet to be met.

Keywords: binomial distribution, indicator-level targets, metric-level targets, "sensitive" species, species-specific metrics.

Introduction

Emerging concerns about the impact of fishing on marine ecosystems (Jennings and Kaiser, 1998; Hall, 1999; Ormerod, 2003) have precipitated the need for an ecosystem approach to management (EAM) (Gislason *et al.*, 2000; Sainsbury and Sumaila, 2001; Hall and Mainprize, 2004; Jennings, 2004; Cury and Christensen, 2005; Garcia and Cochrane, 2005). Although tasked with developing ecological objectives for the North Sea, the Oslo/Paris Commission (OSPAR) does not have the legislative competence to manage fisheries where such management might be necessary to achieve these objectives (Misund and Skjoldal, 2005; Johnson, 2008; Heslenfeld and Enserink, 2008). The European Union Marine Strategy Framework Directive (MSFD) is intended to "... contribute to coherence between different policies and foster the integration of environmental concerns into other policies, such as the Common Fisheries Policy, ... " (EC, 2008). The MSFD therefore explicitly requires fishing activity to be managed, through the Common Fisheries Policy, so that conservation objectives for the broader marine ecosystems might also be achieved.

Descriptor 1 (D1) of the MSFD requires "good environmental status" (GES) with regard to "the maintenance of biodiversity" to be achieved by 2020 (EC, 2008). Indicators have been stipulated at species, habitat, and ecosystem ecological levels (EC, 2010; Table 1). Demersal fish communities consist mainly of mobile species so neither the habitat-level indicators, nor the single

Table 1. Levels, criteria and broad indicator classes proposed for Descriptor 1 "Biological diversity is maintained" of the Marine Strategy Framework Directive (EC, 2010).

Descriptor	Level	Criterion	Indicator Class
1	Species	1.1 Species distribution	1.1.1 Distributional range[a]
			1.1.2 Distributional pattern within the latter, where appropriate[a]
			1.1.3 Area covered by the species (for sessile/benthic species)[b]
		1.2 Population size	1.2.1 Population abundance and/or biomass, as appropriate[a]
		1.3 Population condition	1.3.1 Population demographic characteristics (e.g. body size or age class structure, sex ratio, fecundity rates, survival/ mortality rates)[a]
			1.3.2 Population genetic structure, where appropriate[c]
	Habitat	1.4 Habitat distribution	1.4.1 Distributional range[b]
			1.4.2 Distributional pattern[b]
		1.5 Habitat extent	1.5.1 Habitat area[b]
			1.5.2 Habitat volume, where relevant[b]
		1.6 Habitat condition	1.6.1 Condition of the typical species and communities[b]
			1.6.2 Relative abundance and/or biomass, as appropriate[b]
			1.6.3 Physical, hydrological and chemical conditions[b]
	Ecosystem	1.7 Ecosystem structure	1.7.1 Composition and relative proportions of ecosystem components (habitats and species)[d]

[a]The four species-level indicators considered in this paper. [b]Habitat-level indicators, or indicators explicitly directed towards benthic invertebrates and other sessile species, considered here to be of little relevance to fish communities. [c]The single species-level indicator for which insufficient information is available to develop a fish community species-level biodiversity indicator. [d]The ecosystem-level indicator addressed elsewhere.

species distribution indicator explicitly directed at "sessile/benthic species" (1.1.3), are pertinent. Genetic variability has been examined in a few commercial fish populations (Mork *et al.*, 1985; Giæver and Forthun, 1999; Shaw *et al.*, 1999; Nesbø *et al.*, 2000; Hutchinson *et al.*, 2001; Nielsen *et al.*, 2009), but temporal variation has rarely been assessed (e.g. Poulsen *et al.*, 2006), so appropriate fish biodiversity metrics could not be derived to support this D1 indicator. We will consider ecosystem-level indicators and targets in a future analysis, and focus here on selecting *species-specific metrics* (SSMs) to fulfil the function of the remaining four *species-level indicators* (SLIs) (Table 1). We suggest a procedure for setting trends-based *metric-level targets* (MLTs) for individual SSMs, and setting *indicator-level targets* (ILTs) for the number of SSMs required to meet their MLTs (see Table 2 for a summary of terminology, definitions and acronyms used in this paper).

Assessment survey data

Groundfish surveys have been carried out for decades (Heessen, 1996; Heessen and Daan, 1996), generating abundance-at-length data that are ideal for determining metrics to populate the four SLIs (Trenkel and Cotter, 2009). The first quarter (Q1) international bottom trawl survey (IBTS) is used to calculate the North Sea Large Fish Indicator (LFI) on which the current fish community OSPAR Ecological Quality Objective (EcoQO) is based (Greenstreet *et al.*, 2011; 2012; Heslenfeld and Enserink, 2008). We use the same dataset to exemplify its potential in supporting MSFD D1 indicators. Sampling variation affects biodiversity-related metrics (Greenstreet and Piet, 2008), so groundfish survey data generally require standardization prior to analysis (Jouffre *et al.*, 2010). Data from a 'standard' survey area were therefore analysed (Supplementary Annex 1).

SSM selection

The proportion of ICES statistical rectangles surveyed each year in which particular species were recorded can be used as a SSM of variation in "distributional range" (SLI 1.1.1; Table 1). SSMs of species "population abundance and/or biomass" (SLI 1.2.1; Table 1) can be generated directly from abundance-at-length data (e.g. Greenstreet et al., 2012). The mean:variance ratio (an index of dispersion/contagion) (Southwood, 1978) of ICES rectangle species abundance/biomass data in occupied rectangles can be used as a SSM of "distributional pattern" within the occupied range (SLI 1.1.2; Table 1). Spawning stock biomass, used to monitor variation in the 'state' of commercial fish stocks (e.g. Piet and Rice, 2004), is not routinely assessed for non-target species. However, knowing length-at-first-maturity for all species recorded in the Q1 IBTS (Supplementary Annex 2), the proportion of species' population biomass exceeding its length-at-first-maturity can provide an estimate of the fraction of each species' population that is sexually mature. This can fulfil the "population demographic" indicator role (SLI 1.3.1; Table 1).

Management goals – recovery

Derivation of MLTs

Fish landings into the UK increased threefold through the first half of the 20th century then declined to a level in 2008 lower than at any time in the previous 120 y. Landings per unit fishing power, an indicator of fish abundance, declined by >90% between 1890 and 1980 with little change since (Thurstan *et al.*, 2010). Marked fishing-induced changes in North Sea demersal fish community structure were apparent by the middle of the 20th century (Greenstreet and Rogers, 2006). Species with 'slow-type' life-history traits (large-bodied, slow growing, late age and large size at first maturity, low fecundity, etc.) are particularly sensitive to fishing mortality (Jennings *et al.*, 1998; Gislason *et al.*, 2008; Le Quesne and Jennings, 2012), and by the 1970s populations of such species had declined markedly (Greenstreet and Hall, 1996; Rijnsdorp, *et al.* 1996; Philippart, 1998; Walker and Hislop 1998; Greenstreet *et al.*, 1999; Frisk *et al.*, 2001; van Strien *et al.*, 2009), causing a shift towards 'faster' life-history trait composition among the demersal assemblage as a whole (Jennings *et al.*, 1999; Greenstreet and Rogers, 2000). Predatory fish biomass in North

Table 2. Summary of terminology and acronyms, and over-view of logic underlying the derivation of non-parametric trends-based *metric-level targets* (MLTs) for each *species-specific metric* (SSM), which then determines effective *species-level indicators* (SLIs) as the number of SSMs meeting their MLTs, and use of the binomial distribution to set objective *indicator-level targets* (ILTs) for each SLI.

1. The EC Decision document (EC, 2010) defines indicators at three ecological levels for Descriptor 1: species, habitats and ecosystems. To fulfil the function of each *species-level indicator* (SLI), *species-specific metrics* (SSMs) are required.
   - Thus SLI 1.2.1 is "population abundance and/or biomass", so SSMs of abundance for a defined list of species are required; cod (*Gadus morhua*) abundance would be one SSM, saithe (*Pollachius virens*) abundance a second SSM, spurdog (*Squalus acanthias*) abundance a third SSM, and so on.
2. For each SSM, a *metric-level target* (MLT) must be set. Ideally the MLT would be an absolute SSM value representing "good environmental status" (GES).
   - Thus, for cod, if a population abundance of 5.6×10^9 was considered to represent GES, this abundance value would be set as the MLT for the cod SSM.
3. But where absolute values representing GES cannot be determined empirically for particular SSMs, trends-based MLTs are a pragmatic alternative. Here a non-parametric approach to setting trends-based MLTs is used. For each individual SSM, a trends-based MLT for recovery, such as '*the current assessment year' SSM value should be in the upper 25 percentile of all SSM values in the full time-series 'reference period*' might be set.
   - So if the cod abundance time series started in 1983 and the 'current assessment year' is 2008 (usually the last year for which data are available) cod abundance in 2008 should be amongst the top 25% of all cod abundance values recorded from 1983 to 2008 for the cod abundance MLT to be met.
4. Each SLI is then the number of associated SSMs actually meeting their MLTs.
   - Thus of the defined list of species, the 1.2.1 "population abundance" SLI would be the number (or proportion) of individual "population abundance" SSMs meeting their specified upper-percentile range MLTs.
5. The *indicator level target* ILT is set such that, knowing the number of individual SSMs analysed (e.g. the specified list of species) and the probability of any individual SSM meeting its MLT, observing such an SLI value would represent a statistically significant (e.g. less than 5% chance) departure from the binomial distribution.
   - Thus if the specified list contained 25 species for which population abundance SSMs could be determined and the SLI was 13 (i.e. SSMs for 13 of the species had met their MLTs), then this would represent a significant departure from the binomial distribution (see Table 4), leading to the conclusion that the ILT for the 1.2.1 "population abundance" SLI had been met.

Atlantic marine ecosystem also declined markedly by the 1960s (Christensen *et al.*, 2003).

Although the longest-running North Sea groundfish survey still operating, the Q1 IBTS only commenced in 1983, well after major changes in the demersal fish community had occurred. When absolute target values cannot be derived empirically because data to assess indicator values prior to anthropogenic change are not available, setting trend directions provides a pragmatic alternative (Jennings and Dulvy, 2005; Link, 2005; Shin *et al.*, 2005). The current 'state' of the North Sea demersal fish community is clearly unsatisfactory, particularly in respect of 'sensitive' species with 'slow type' life-history traits, and even though the satisfactory state cannot be precisely defined, improvement is obviously necessary. Life-history trait analysis was used to identify 33% of the 119 demersal fish species sampled by the Q1 IBTS with the 'slowest-type' traits (Supplementary Annex 2) for inclusion in the SLI assessment. Anticipating positive mitigation trends, trends-based MLTs can then be set for each of these 40 'sensitive' species' SSMs (Table 3).

For many species, metric trends were not monotonic invalidating the use of standard parametric trend analysis techniques. An alternative non-parametric approach is to treat each SSM's entire time-series as the 'reference period'. MLTs can then be set for the last year in the time-series, or 'current assessment year'. For example, "*The 'current assessment year' SSM value should be in the upper 25 percentile of all SSM values in the full time-series 'reference period'*" (see Table 2). Figure 1a illustrates such a MLT applied to three 'sensitive' species' "population abundance" SSMs. Two species, halibut (*Hippoglossus hippoglossus*) and spotted ray (*Amblyraja radiata*), would meet their MLTs, but, after first increasing, the anglerfish (*Lophius piscatorius*) SSM then declined, so that in the 'current assessment year' it would fail to meet its MLT. Other upper-percentile ranges (e.g. upper 15%, upper 35%, or upper 50%) might also be considered as potential MLTs depending on the level of ambition considered desirable for each SSM.

Derivation of ILTs

How many individual SSMs need to meet their MLTs to conclude that ILTs for each SLI had successfully been achieved? Assessing compliance with the North Sea EcoQO for commercial fish species, "Spawning stock biomass of commercial fish species in the North Sea should be above precautionary reference points for commercial fish species where these have been agreed by the competent authority for fishery management" (Heslenfeld and Enserink, 2008), presented a similar dilemma. The definition was met by 17 stocks, but how many are needed to exceed precautionary biomass reference points for the overall EcoQO to be achieved? Given a false alarm rate of 25%, setting a compliance target of 100% presents a high risk of apparent failure, even if all stocks were indeed above precautionary biomass levels. A target of 80% reduces the risk of failing the EcoQO simply through false alarms (Piet and Rice, 2004). So, for any given number of SSMs for each SLI, how might the ILT, the number of SSMs needing to meet their upper-percentile MLTs, be determined?

Knowing the probability of an event happening, the number of such events occurring in a given number of trials is predicted by the binomial distribution. A Brownian random-walks model, incrementing the simulated SSM value by a normally distributed (with mean of 0) random number at each of 20 000 time steps, was used to estimate the probability of the last datum in an autocorrelated time-series falling in any specified upper-percentile range under the null hypothesis of a random step progression (Maxwell and Jennings, 2005). For each potential upper-percentile

Table 3. Derivation of trends-based MLTs for each SSM applied to 'sensitive' demersal fish species in the North Sea.

EC Indicator	Metric	Perturbed state condition	Trend target direction
1.1.1 Distributional range	Proportion of surveyed ICES rectangles occupied	Depressed – population reduced and only prime habitat sites occupied	positive
1.1.2 Distributional pattern within range	Mean:variance ratio of abundance in occupied rectangles by numbers	Depressed – density remains high in prime habitat site, but few occupied marginal habitat sites hold low densities leading to high variance	positive
1.1.2 Distributional pattern within range	Mean:variance ratio of abundance in occupied rectangles by biomass	Depressed – density remains high in prime habitat site, but few occupied marginal habitat sites hold low densities leading to high variance	positive
1.2.1 Population abundance and/or biomass	Abundance	Depressed – population abundance reduced by unsustainable mortality	positive
1.2.1 Population abundance and/or biomass	Biomass	Depressed – population biomass reduced by unsustainable mortality	positive
1.3.1 Population demographic characteristics	Proportion of biomass greater than length-at-first maturity	Depressed – spawning component in slow-growing late-maturing species reduced by unsustainable mortality	positive

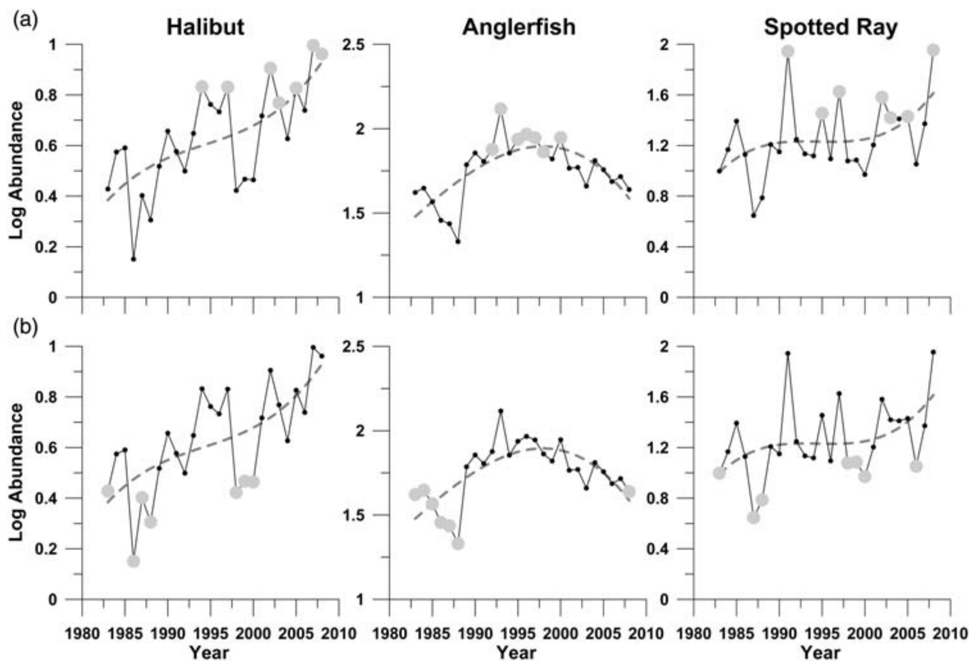

Figure 1. Variation in "population abundance" species-specific metric (SSM) values for three 'sensitive' species in the North Sea derived from Q1 IBTS data. Grey dashed lines are 3rd degree polynomials fitted to highlight the different underlying trends. Large light grey dots indicate: **(a)** SSM values falling in the upper 25 percentile of all values in the whole time-series 'reference period' **(b)** SSM values falling in the lower 25 percentile of all values in the whole time-series 'reference period'.

range MLT, the random-walks model was repeated 200 000 times to estimate the corresponding probabilities (Table 4). The binomial distribution can now be used to ascertain how many such events should be observed among any given number of SSMs for there to be a $< 5\%$ probability of this happening by chance (Table 4). Demonstrating significant departure from the binomial distribution therefore represents the ILT; if these numbers of SSMs, or more, meet their MLTs, then the SLI has met the ILT (see Table 2).

Varying the upper-percentile range MLTs clearly influences the number of SSMs required to meet their MLTs for departure from the binomial distribution to be statistically significant (Table 4). Exploration of this balance point could allow the most risk-averse (of false alarms) strategy to be determined. For a given number of SSMs, making the MLTs more ambitious reduces the proportion of SSMs required to meet their MLTs in order for ILTs to be achieved (Table 4). It seems counter-intuitive, but increasing MLT ambition makes meeting the ILT easier. This is because variance of the binomial distribution is determined as $np(1 - p)$, where n is the number of 'sensitive' SSMs and p the probability of each SSM achieving its MLT, so variance increases appreciably as p increases, particularly at smaller n (Table 4). The more

Table 4. For a given number of 'sensitive' species analysed, the number (and percentage in parenthesis) of SSMs required to meet specified upper- (or lower-) percentile MLTs for the probability of observing such a departure from the binomial distribution to be less than 5%.

	Metric values in 'current assessment year' should lie within the upper (or lower):			
Number of assessed 'sensitive' species	**15% of all values ($p = 0.253$)**	**25% of all values ($p = 0.332$)**	**35% of all values ($p = 0.403$)**	**50% of all values ($p = 0.500$)**
10	6 (60%) *1.890*	7 (70%) *2.218*	8 (80%) *2.406*	9 (90%) *2.500*
15	8 (53%) *2.835*	9 (60%) *3.327*	10 (67%) *3.609*	12 (80%) *3.750*
25	11 (44%) *4.725*	13 (52%) *5.544*	15 (60%) *6.051*	18 (72%) *6.250*
35	14 (40%) *6.615*	17 (49%) *7.762*	20 (57%) *8.421*	23 (66%) *8.750*
40	16 (40%) *7.560*	19 (48%) *8.871*	22 (55%) *9.624*	26 (65%) *10.000*
50	19 (38%) *9.450*	23 (46%) *11.089*	27 (54%) *12.030*	32 (64%) *12.500*

If the indicated numbers of SSMs lie in the upper-percentile range then this provides evidence that introduced management measures have achieved a recovery among a significant fraction of the 'sensitive' SSMs analysed. If the indicated numbers of SSMs lie in the lower-percentile range then this provides evidence that continued overfishing is negatively impacting a significant fraction of the 'sensitive' SSMs analysed (see text for details). Figures in italics indicate calculated variance of the binomial distribution for each combination of the number of assessed 'sensitive' species and probability associated with the 'current assessment year' SSM value lying within the specified upper- or lower-percentile MLT ranges.

ambitious the individual species-specific MLTs, and so smaller value of p, the greater the statistical power to demonstrate a significant departure from the binomial distribution. This could be a key consideration when determining appropriate MLTs (Nicholson and Jennings, 2004; Maxwell and Jennings, 2005). Politically one might wish to set more ambitious MLTs for the individual SSMs, but at the same time not want the overall ILT to appear less stringent. To counter this, the significance level for assessing departure from the binomial distribution could simply be adjusted, from 5% to the 1% probability level.

Management goals – prevent further decline

Recovery responses to remedial management may involve long time-lag delays; for example LFI responses to varying fishing mortality in both the North and Celtic Seas were lagged by >10 y (Daan et al, 2005; Greenstreet *et al.*, 2011; Shephard *et al.*, 2011; Greenstreet *et al.*, 2012). Fishing mortality in the North Sea started to decline in 1986 so real improvement in D1 metrics might only be expected from around 2000 onwards. The reduction in fishing mortality has also been gradual: a 60% decline over 22 y. A range of species responses is therefore likely; the least 'sensitive' species recovering soonest with only minimal reductions in mortality necessary to initiate recovery, and the most 'sensitive' species, those with the 'slowest' life-history traits, requiring a larger reduction in fishing mortality before commencing any recovery. Recovery in populations of the more 'sensitive' species would therefore have been more recent, and fishing mortality rates may still remain too high for some of the most 'sensitive' species in the community (Le Quesne and Jennings, 2012). Although fishing mortality across the targeted species in the community may have declined since 1986, levels of fishing effort remained almost unchanged until 2000, when the implementation of specific management action brought about a 40% reduction by 2004 (Greenstreet *et al.*, 2009). Fishing pressure on many non-target species may only have eased with this reduction in fishing effort (Piet *et al.*, 2009).

Derivation of MLTs

Rather than setting MLTs associated with demonstrating recovery, perhaps initial steps should be to demonstrate no further decline. Individual species-specific MLTs can be reworded to reflect this, e.g. "The current 'assessment year' SSM value should not fall in *the* lower *25 percentile of all values in the full time-series 'reference period*'". This is illustrated using the same three 'sensitive' species (Figure 1b). Rarely over recent years has the recovering halibut failed to meet a MLT aimed at 'stopping further decline'. It is also clearer that prospects for the more variable spotted ray have indeed improved; not only has this species met a MLT for recovery in the last 'current assessment year' (Figure 1a), but over the last eight years the frequency at which it failed to meet a MLT for 'stopping further decline' has reduced. However, this alternative MLT underlines the seriousness of the anglerfish situation. This species would now fail this 'stop further decline' MLT. Again, depending on desired level of ambition, other lower-percentile ranges (e.g. lower 15%, lower 35%, or lower 50%) might be considered.

Derivation of ILTs

In using the binomial distribution to set ILTs for this alternative MLT two aspects need to be considered. First, should the number of SSMs falling into the stipulated lower-percentile range be a significant departure from the binomial distribution on the high side, this would constitute strong evidence that current management was actively driving 'sensitive' fish species in the wrong direction: clear evidence of continued over-exploitation. For this scenario, then the data given in Table 4 provide the required information. Consider an example of 40 individual 'sensitive' SSMs, and a stipulated 'stop further decline' MLT of "*The 'current assessment year' SSM value should not fall in the* lower *25 percentile of all values in the full time-series 'reference period*'"; the probability of this occurring in respect of each individual SSM would again be 0.332. So should we observe 19 'current assessment year' SSM values lying within the lower 25 percentile of their 'reference period' ranges, then this would imply ongoing over-fishing at a level that was actively continuing to reduce demersal fish biodiversity.

However, to demonstrate successful management to stop further decline, what is needed is the converse of this. How large does the number of species that lie *outside* the specified lower-percentile range have to be in order for this to be a significant departure from the binomial distribution? If the probability of the 'current assessment year' SSM value lying within the lower 25 percentile of its full time-series range of values is 0.332, then the probability of it lying outside the lower 25 percentile, i.e. in the

Table 5. For a given number of 'sensitive' species analysed, the number (and percentage in parenthesis) of SSMs required to lie outside specified lower-percentile MLTs for the probability of observing such a departure from the binomial distribution to be less than 5%.

Number of 'sensitive' species	Metric values in 'current assessment year' should lie outside the lower:			
	15% of all values ($P = 0.747$)	25% of all values ($P = 0.668$)	35% of all values ($P = 0.597$)	50% of all values ($P = 0.500$)
10	10 (100%) *1.890*	10 (100%) *2.218*	9 (90%) *2.406*	9 (90%) *2.500*
15	15 (100%) *2.835*	14 (93%) *3.327*	13 (87%) *3.609*	12 (80%) *3.750*
25	23 (92%) *4.725*	21 (84%) *5.554*	20 (80%) *6.015*	18 (72%) *6.250*
35	31 (89%) *6.615*	29 (83%) *7.762*	27 (77%) *8.421*	23 (66%) *8.750*
40	35 (88%) *7.560*	33 (83%) *8.871*	30 (75%) *9.624*	26 (65%) *10.000*
50	43 (86%) *9.450*	40 (80%) *11.089*	36 (72%) *12.030*	32 (64%) *12.500*

Observing such numbers, or more, of the individual SSMs lying outside the specified lower-percentiles provides evidence that introduced management measures have stopped declines in SSM values among a significant fraction of 'sensitive' SSMs analysed. Figures in italics indicate calculated variance of the binomial distribution for each combination of the number of assessed 'sensitive' species and probability associated with the 'current assessment year' SSM value lying outside the specified lower-percentile MLT ranges.

upper 75 percentile, is $1.0 - 0.332 = 0.668$, and so on for other potential lower-percentile ranges and associated probabilities. For any given number of 'sensitive' SSMs analysed, and applying the $1 - p$ probabilities (Table 5), the number of 'current assessment year' SSM values needing to fall outside the specified lower-percentile range for this to be a significant departure (at $P < 0.05$) from the binomial distribution can be determined (Table 5). Seeing this would be strong evidence that further decline had been stopped among a significant fraction of the 'sensitive' species assessed. It is worth noting that in both Tables 4 and 5, because the probabilities illustrated were either p or $1 - p$, the variances in both sets of examples were the same.

Case study: demersal fish in the Greater North Sea

This protocol is now applied to Q1 IBTS data to assess recent trends in six SSMs (see Table 3) in the North Sea demersal fish assemblage.

Selection of "sensitive" species for which to derive SSMs

Based on the criterion that species should be recorded in at least half of the years of the time-series, data were considered adequate for reliable assessment for only 27 of the 40 'sensitive' species. Consequently, 13 of perhaps the rarest and potentially most threatened species in the community were not assessed. We examined the possibility that this might bias our analysis; that the 27 species assessed might be amongst the least sensitive of the 40 'sensitive' species. However, ranking the 40 'sensitive' species from least to most sensitive and determining where in this ranking the 27 species we analysed lay suggested no indication of bias ($\chi^2 = 0.406$, 3 d. f., $p \approx 0.9$, n. s.). The 27 species sampled well enough to support assessment were an adequate subsample of the full suite of 40 potential 'sensitive' species, so there was no reason to believe that the 13 'sensitive' species we did not assess might behave substantively differently to the 27 'sensitive' species that we did.

Management goals – recovery

Each year in turn from 2001 to 2008 was considered the 'current assessment year', and in each case the 'reference period', used to define the upper 25 percentile range MLT, was the full time series from 1983 up to and including the year in question. Similar consistent trends were apparent for four SLIs, "distributional range", "population abundance", "population biomass" and "population demographic characteristics", with variable but low numbers of SSMs meeting their MLTs over the period 2001–2006, followed by a marked increase in 2007 and 2008 (Figure 2). However, the number of MLTs being met did not constitute a significant ($p < 5\%$) departure from the binomial distribution; although the trend is moving in the right direction, ILTs have yet to be met. Both "distribution pattern within range" SLIs were highly variable, and on occasion the number of SSMs meeting their MLTs was sufficient to achieve statistical significance with respect to the ILT (Figure 2). However, the trends were not consistent. At present we do not consider performance of the mean:variance metric to be well enough understood for it to support statutory commitments and be used as a D1 metric to implement the MSFD. Either further developmental work is required to make mean:variance metrics operational, or alternative metrics should be used (e.g. Blanchard *et al.*, 2005; Rindorf and Lewy, 2012).

Management goals – prevent further decline

Figure 3 shows the number of individual SSMs meeting the alternative MLT of "*The 'current assessment year' SSM value should not fall in the* lower *25 percentile of all values in the full time-series 'reference period'*" (i.e. the plots show the numbers of SSMs falling in the upper 75 percentile of all values). The two "distribution pattern within range" SLIs frequently met their ILTs over the period 2001–2008. However, having just declared a lack of confidence in the mean:variance ratio metric, we direct attention to the four remaining SLIs. Here the situation is less convincing, with only one SLI meeting its ILT once in the eight annual assessments (1.2.1 "Population abundance": Figure 3d). On the basis of these four SLIs, we have no evidence at present to suggest that remedial management has successfully prevented further decline among a significant proportion of the 27 'sensitive' species assessed.

Whilst we cannot demonstrate that the current management regime is actually preventing decline, the question can be turned around; is the current management regime actually causing ongoing deterioration in biodiversity, i.e. are current fishing mortality levels sufficiently high as to still be causing declines among a significant fraction of 'sensitive' fish species? Or in other words, does the number of SSM values actually falling in the lower 25 percentile of all values in their full time-series 'reference periods' represent a significant departure from the expected number predicted by the binomial distribution? Figure 4 shows that this is not the case; there is therefore no evidence to suggest that the current

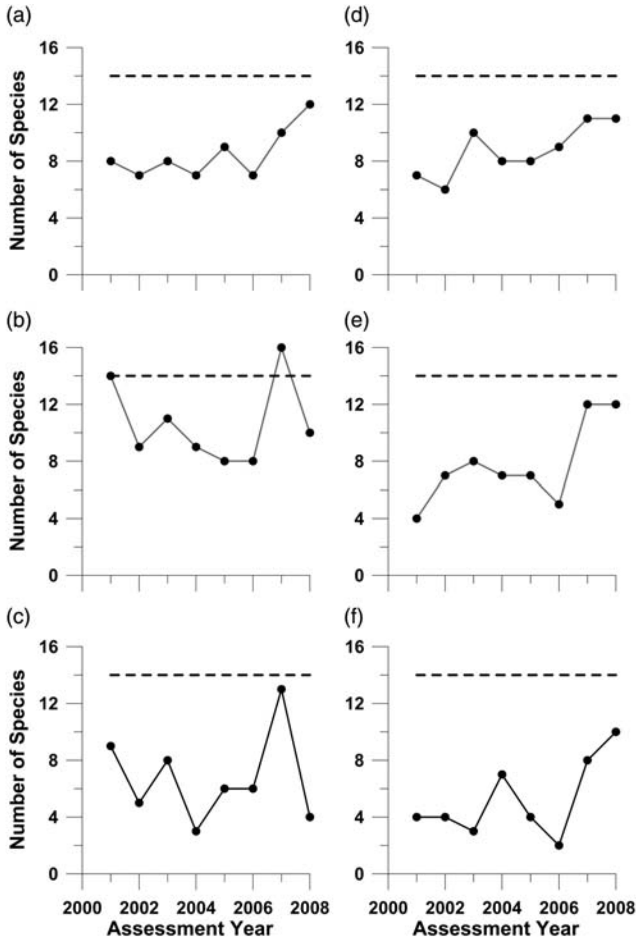

Figure 2. Number of individual SSMs meeting their 'recovery' MLTs. "*The 'current assessment year' SSM value should be in the top 25 percentile of all values in the full time-series 'reference period'*" for each SLI class evaluated: **(a)** 1.1.1 "Distributional range"; **(b)** 1.1.2 "Distributional pattern within range (by numbers)"; **(c)** 1.1.2 "Distributional pattern within range (by biomass)"; **(d)** 1.2.1 "Population abundance"; **(e)** 1.2.1 "Population biomass"; **(f)** 1.3.1 "Population demographic characteristic (proportion of biomass greater than length-at-first-maturity)". Dashed horizontal line indicates the ILT, the number of SSMs meeting their MLTs that represent a significant departure ($p < 0.05$) from the binomial distribution. North Sea case study analysing data for 27 'sensitive' species monitored using Q1 IBTS data.

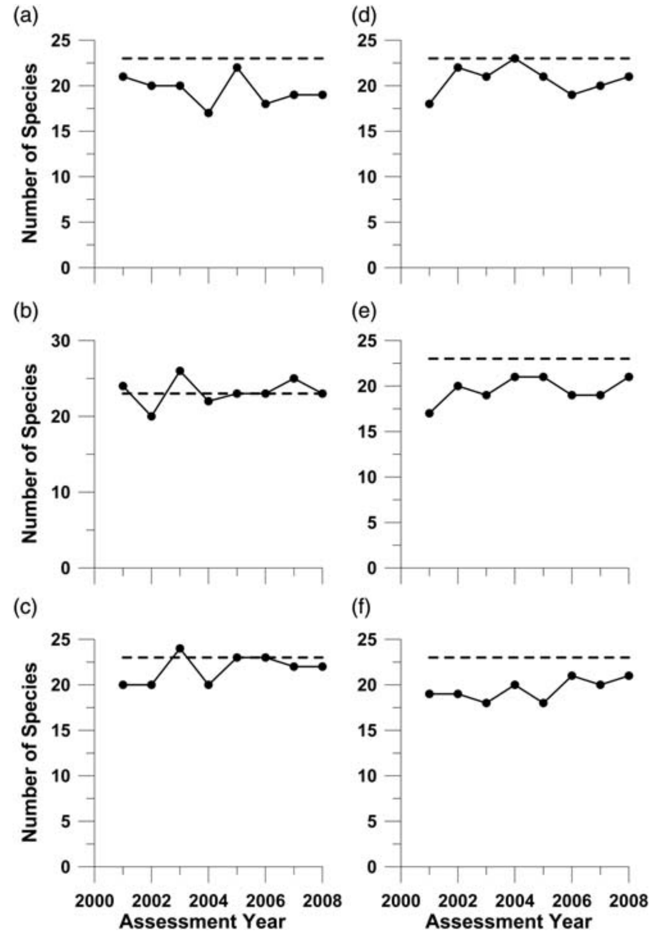

Figure 3. Number of individual SSMs meeting their 'prevent further decline' MLTs. "*The 'current assessment year' SSM value should not fall in the* lower *25 percentile of all values in the full time-series 'reference period'*" (i.e. the number of SSMs falling in the upper 75th percentile of all metric values in the time-series) for each SLI class evaluated: **(a)** 1.1.1 "Distributional range"; **(b)** 1.1.2 "Distributional pattern within range (by numbers)"; **(c)** 1.1.2 "Distributional pattern within range (by biomass)"; **(d)** 1.2.1 "Population abundance"; **(e)** 1.2.1 "Population biomass"; **(f)** 1.3.1 "Population demographic characteristic (proportion of biomass greater than length-at-first-maturity)". Dashed horizontal line indicates the ILT, the number of SSMs meeting their MLTs that represent a significant departure ($p < 0.05$) from the binomial distribution. North Sea case study analysing data for 27 'sensitive' species monitored using Q1 IBTS data.

management regime in the North Sea is actually responsible for an ongoing reduction in fish biodiversity.

At present, therefore, we appear to be in an equivocal situation. We have no evidence to demonstrate that remedial management is actually preventing decline, but equally there is no evidence to suggest that the current levels of exploitation are actually causing ongoing decline. This illustrates the importance of the precise phrasing of the binomial experiment being undertaken. It also emphasizes the need for both analyses. In this case study, the first analysis suggests that we have not yet definitely achieved a solution, but the second implies that we no longer definitely have an ongoing problem.

In Figure 2, the upward inflection in the number of SSMs meeting their specified upper-percentile MLTs tended to occur in the last two assessment years, while in Figure 3, a similar inflection tended to occur in the first or second year of assessment. Remedial management first brings about a cessation of further decline, before initiating actual recovery in metric and indicator values. Whilst seeming trivial, this observation could be important in gauging the time-scales of responses to remedial management (Nicholson and Jennings, 2004; Maxwell and Jennings, 2005). In situations of ongoing decline, setting MLTs and ILTs associated with demonstrating significant recovery may take many years to achieve, while targets based on stopping further decline may be more achievable in the short-term, and prove to be a moral-boosting first step along a long road to eventual recovery.

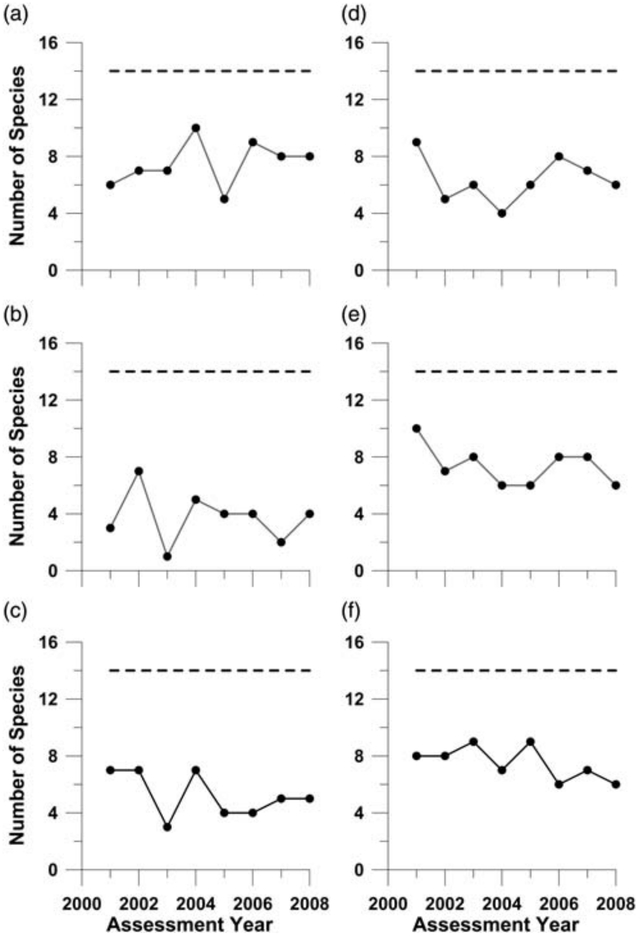

Figure 4. The number of individual SSMs failing to meet their 'prevent further decline' MLTs. " *The 'current assessment year" SSM value should not fall in the* lower 25 *percentile of all values in the full time-series 'reference period'*" (i.e. the number of SSMs falling in the lower 25 percentile of all metric values in the time-series) for each SLI class evaluated: **(a)** 1.1.1 "Distributional range"; **(b)** 1.1.2 "Distributional pattern within range (by numbers)"; **(c)** 1.1.2 "Distributional pattern within range (by biomass)"; **(d)** 1.2.1 "Population abundance"; **(e)** 1.2.1 "Population biomass"; **(f)** 1.3.1 "Population demographic characteristic (proportion of biomass greater than length-at-first-maturity)". Dashed horizontal line indicates the ILT, the number of SSMs meeting their MLTs that represent a significant departure ($p < 0.05$) from the binomial distribution. North Sea case study analysing data for 27 'sensitive' species monitored using Q1 IBTS data.

Persistently failing species

Being unable to demonstrate a cessation of further decline among a significant fraction of the 27 'sensitive' demersal fish SSMs analysed, despite more than 20 y of declining fishing mortality and 10 y of reduced fishing effort in the North Sea (Greenstreet et al., 2009; Greenstreet et al., 2011), prompted us to examine the data to look for species that persistently failed to meet their MLTs. This was rare among the two "distribution pattern within range" SSMs, but more common among the other four SSMs. Three species, catfish (*Anarhichas lupus*), cod (*Gadus morhua*), and spurdog (*Squalus acanthias*), persistently failed the MLT for the two "population size" SSMs and the "distributional range" SSM (Figure 5), and ongoing declining trends were clearly the cause. Lumpsucker (*Cyclopterus lumpus*), ling (*Molva molva*), torsk (*Brosme brosme*), pollack (*Pollachius pollachius*), and Norway haddock (*Sebastes viviparus*) also regularly failed their MLTs for one or other of these SSMs, but not all three. A slightly different suite of species regularly failed the "population demographic" (proportion of biomass greater than length-at-first-maturity) MLT, and again declining trends were apparent among at least four of these species (Figure 6). Despite progress made in reducing the impact of fishing on North Sea demersal fish, mortality rates for some 'sensitive' species remain sufficiently high such that SSM values continue to decline.

Alternative upper- (or lower-) percentile MLTs

The effect of adopting alternative upper- and lower- percentile MLTs, e.g. those illustrated in Tables 4 and 5, was examined. This had negligible effect on our results or conclusions. As expected, increasing MLT ambition reduced the number of SSMs meeting their MLTs, but at the same time the number of SSMs required to meet their MLT in order to demonstrate a significant departure from the binomial distribution was also reduced. These changes tended to counter-balance one another so that there was negligible effect on the frequency of occasions that ILTs were achieved.

Discussion

Generality of method application

We have used a North Sea case study to exemplify our proposal for selecting SSMs, setting trends-based MLTs for these SSMs, and setting ILTs for the number of SSMs required to meet their MLTs. A major strength of the North Sea situation was the availability of near-regional scale survey data and the relatively long duration of its time-series. In other regions where the MSFD applies, relatively recent data may only be available for comparatively short periods. Short time-series do not preclude application of the method we propose; even with a ten-year time-series it would still be possible to set upper-percentile ranges as SSM trends-based MLTs. Provided a sufficient number of sensitive species can be identified to fulfil the SSM roles, then the procedure to establish the number of SSMs required to meet their MLTs that represents a significant departure from the binomial distribution is still applicable. If relatively short recent time-series are all that is currently available, these time-series will only get longer as monitoring proceeds. The MSFD requires that GES be attained by 2020; if only 10 y of data are available now, then by 2020 the time-series would cover 18 y. Long time-lags for recovery (e.g. Greenstreet *et al.*, 2011; Shephard *et al.*, 2011) suggest that if management measures are only implemented in 2016, the need for ongoing monitoring, assessment and remedial management could continue long past 2020. Provided the required monitoring programmes are established immediately, their fitness-for-purpose can only improve.

Our approach need not only be restricted to the assessment of fish biodiversity under the MSFD. We can think of no reason why it should not be equally applicable to other marine taxa. The only requirements are adequate monitoring data and a theoretically sound *a priori* reason for setting a trends-based target for the species concerned.

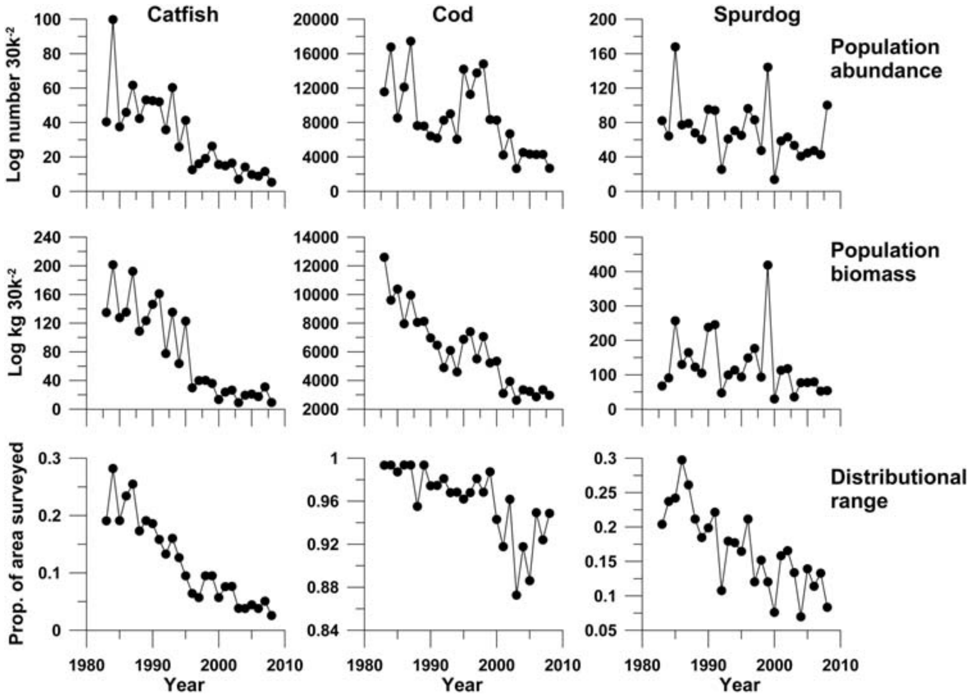

Figure 5. Temporal trends in the species-specific "population abundance", "population biomass" and "distributional range" metrics of catfish, cod and spurdog.

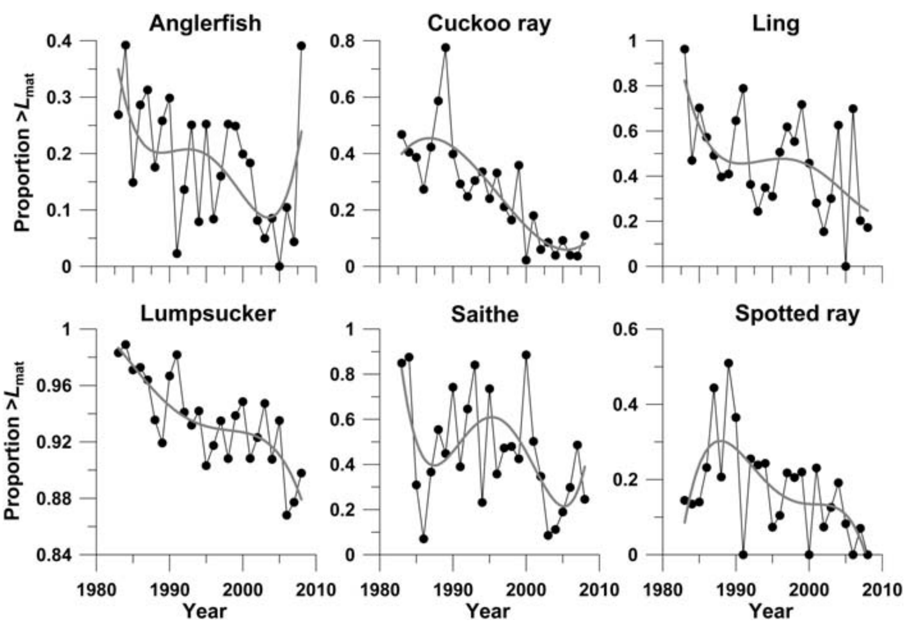

Figure 6. Temporal trends in the species-specific "population demographic" metric (proportion of biomass greater than the length of first maturity) of anglerfish, cuckoo ray (*Leucoraja naevus*), ling, lumpsucker, saithe (*Pollachius virens*), and spotted ray (*Raja montagui*). Grey lines show fitted 4th degree polynomial smoothers to highlight underlying trends in the data.

Representativeness of the 27 assessed 'sensitive' species

The 27 'sensitive' species we assessed proved to be an unbiased sub-sample of the total of 40 'sensitive' species recorded in the Q1 IBTS. This implies that, if in the future management measures were to achieve increases in abundance among a significant fraction of the 27 assessed species, then a similar proportion of the 13 non-assessed species should be similarly affected, raising the probability of their 'detection' in the survey. Eventually, with each additional survey, this would result in some of these 13 species being sampled in more than the 50% of surveys, which was our criterion for selection for assessment. Meeting ILTs for abundance and biomass should therefore result in an increase in the number of SSMs available for assessment. The converse of this is that some of the 13 non-assessed species may be so sensitive that they continue to undergo population declines (e.g. Le Quesne and Jennings, 2012). If data for such species are deemed inadequate to support target-setting and monitoring programmes today, then ongoing declines will not improve their situation. The data for these species will remain inadequate and we will not be able to assess changes in their status. However, the sub-sample of 27 analysed 'sensitive' species did include species with continuing declining SSM trends. Our assessed sub-sample was therefore also representative of this situation; failure to halt declines in some of these representative species is indeed indicative of continuing problems among some of the non-assessed species.

Independence of SSMs

In using the binomial distribution to determine the number of SSMs required to meet their individual MLTs, and thus achieve the ILT, there is an underlying assumption of independence among the individual SSMs. But the species analysed have been selected because of their 'sensitive' to additional mortality caused by human activities. In setting the trends-based MLTs, the underlying assumption is that they should *all* respond in a particular way to remedial management (Table 3). Does this undermine the assumption of independence between the SSMs? We argue not. The manipulation of human pressure on demersal fish biodiversity, through varying the management regime (little restriction through to considerable restriction on landings and/or effort), can be considered as the 'variable treatment' in an 'experiment'. We hypothesize that 'varying the treatment' in a particular way should cause the SSMs to respond in a predictable and uniform manner, and we test this hypothesis using the binomial distribution. The question really is whether, in the absence of any human intervention (no fishing and so no fisheries management) the 27 (in this case) 'sensitive' species might be expected to vary independently? In reality we have little evidence to suggest that they shouldn't, and lots to suggest that they might.

Demersal fish species have their own particular habitat requirements in terms of preferred temperature regime, depth range and sediment characteristics (Greenstreet *et al.*, 1997; Magnussen, 2002; Perry *et al.*, 2005; Hinz, *et al.*, 2006; Dulvy *et al.*, 2008; Righton *et al.*, 2010), giving rise to distinct differences in species' distributions (Heessen and Daan, 1996; Hinz *et al.*, 2003; Hedger *et al.*, 2004), so that different species are subjected to quite different hydro-dynamic regimes (Turrell, 1992; Berx and Hughes, 2009). Diets vary between different demersal fish species so that they are affected in different ways by variation in the abundance of different prey (Hislop, 1997; Greenstreet *et al.*, 1998; Floeter *et al.*, 2005; Floeter and Temming, 2005). Reproductive mode and spawning period vary between different demersal fish so that their larvae experience quite different hydrodynamic environments and respond differently to different environmental drivers; temporal variation in recruitment across species is therefore rarely correlated (Philippart *et al.*, 1996). Finally, 'sensitive' species also vary in their vulnerability to fishing pressure, so that the responses of different species to particular changes in fishing pressure are also expected to differ (Le Quesne and Jennings, 2012).

Failure to demonstrate recovery or cessation of decline

Le Quesne and Jennings (2012) estimate that fishing mortality in the Celtic Sea may remain sufficiently high as to place many of the more sensitive species in the community below conservation reference points. The same may be true in the North Sea, despite declines in fishing mortality in recent decades (Greenstreet *et al.*, 2011). In using the binomial distribution to set ILTs, we assume that the species involved all have the same probability of meeting their MLTs. In reality this is clearly not the case; mortality rates in some of the species assessed are still too high, causing continued population decline or preventing recovery. This makes it more difficult to demonstrate a significant departure from the binomial distribution and meet the ILT. Consider an MLT of "*The 'current assessment year' SSM value should lie within the upper 25 percentile of the full time-series 'reference period' range*". Table 4 indicates that, with 25 SSMs, 13 (or 52%), need to meet this MLT for there to be a <5% probability of observing such a result simply by chance, so demonstrating a significant departure from the binomial distribution. But if in reality, five species have no hope of recovering because their mortality rates remain too high, then a higher recovery rate of 62% would be required among the other 20 species in order for the ILT to be achieved.

As mortality is gradually reduced, more and more 'sensitive' species will benefit as mortality rates progressively decline to levels that each successive species can sustain (Le Quesne and Jennings, 2012). However, if mortality rates applied to 'commercial' and 'sensitive' species can not be decoupled, safeguarding the most sensitive species in the Celtic Sea fish community may require up to 65% of potential yield-per-recruit to be sacrificed (Le Quesne and Jennings, 2012). The reduction in fishing mortality necessary to allow the most sensitive species in the community to recover could therefore be unsustainable as far as the economics of the fishing industry is concerned. This may be politically unacceptable and contrary to the intent of the MSFD to promote continued "sustainable use of marine goods and services by present and future generations". However, sustainable use has to be compatible with achieving GES, such that "the capacity of marine ecosystems to respond to human-induced changes is not compromised" (EC, 2008, Chapter 1, Article 1, paragraph 3). The MSFD is not intended to be a legislative tool to restrict human activities in marine ecosystems to such low levels that the original pristine state might be restored. If economic sustainability of the fishing industry into the future requires relatively high levels of yield-per-recruit, then loss of the most sensitive species in the demersal fish community could be the price that has to be paid. A further question then is how many of these 'sensitive' species can we afford to lose before the capacity of marine ecosystems to respond to human-induced changes is threatened?

Unless technical measures can be introduced to decouple mortality rates applied to 'sensitive' and 'commercial' species, providing succour to the fishing industry and permitting fishing mortality rates that are higher than can be tolerated by some of the most 'sensitive' demersal fish species comes at the cost of making it more difficult to achieve ILTs. Greater measures may be necessary to promote recovery among the 'sensitive' species that are capable of sustaining such levels of mortality, or further reductions in mortality may be required in order to stimulate recovery in one or two more of these most 'sensitive' species. Additional protection to safeguard remnant populations of especially sensitive and depleted species could help to stop further decline; for example, spatial measures (marine protected areas: MPAs) to protect remnant populations of large mature female common skate. However, establishment of such MPAs would not devolve member states of their obligation to address the issue of unsustainable human pressure on marine ecosystems at regional scales.

Politically, it would be desirable if the 'state' indicators used in support of the MSFD could reflect the beneficial (or otherwise) effects of management measures over time-scales of one to four years (Nicholson and Jennings, 2004; Maxwell and Jennings, 2005). But 'state' indicators monitor change in the status of different marine ecosystem components, and if these changes only occur over long periods (Daan *et al.*, 2005; Greenstreet *et al.*, 2011; Shephard *et al.*, 2011; Greenstreet *et al.*, 2012), then this could be a forlorn hope. In adopting an EAM and implementing the MSFD in European waters, politicians may have no alternative but to adopt a long-term perspective.

Trends-based targets and GES

Because the individual SSM MLTs are trends-based, achieving the ILT does not necessarily mean that GES has been achieved in respect of any particular SLI. We still do not know what the GES 'state' actually looks like. What meeting each ILT does imply is that the number of sensitive demersal fish species now on recovery trajectories is significantly more than the number expected simply by chance. This is evidence that management measures to mitigate human impact on the demersal fish assemblage are successfully moving the sensitive species component of the community in the right direction. It is evidence of "improved environmental status". However, setting recovery-related trends-based MLTs in perpetuity is also nonsensical; at some point over-shooting GES is inevitable, almost certainly associated with unnecessarily stringent restriction of human activities. Since the MSFD is just as concerned that marine resources are utilized to their full sustainable potential, this should also be avoided.

Other indicators, for example the ecosystem-level indicator (1.7.1: Table 1), or achieving the OSPAR EcoQO for the LFI (Greenstreet *et al.*, 2011; Shephard *et al.*, 2011), might be used to assess when GES for the whole demersal fish community has been achieved. Making a "leap of faith", one might assume that if the 'state' of the fish community as a whole meets GES, then GES should also have been achieved for its constituent species. If so, then from this point forward, trends-based MLTs for individual SSMs might be relaxed from 'striving for improvement' to just 'maintaining *status quo*'. However, the nature of the relationship between the status of whole communities and the status of the individual species of which they are comprised has yet to be properly explored. At present therefore, such an approach should not be considered operational. Adopting the trends-based approach that we propose would, in the short term, ensure that the remedial management necessary to bring about recovery was implemented immediately; thereby buying more time to determine what GES for 'sensitive' fish species might actually look like.

Supplementary data

The following supplementary material is available at the *ICESJMS* online version of this article:

Annex 1 presents the results of an assessment of variation in spatial coverage by the Q1 IBTS in order to determine a "standardized" sampling area.

Annex 2 presents the results of an analysis of the life-history traits of 119 demersal fish species sampled by the Q1 IBTS in order to derive "sensitivity" scores for each species, enabling these species to be ranked by their sensitivity to additional mortality associated with fishing activity.

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