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Length-based indicators and reference points for assessing data-poor stocks of diadromous trout *Salmo trutta*

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ABSTRACT

Many populations of diadromous fish have declined, but data are limited and there are very few quantitative stock assessments. Length-based indicators (LBIs) and reference points (RPs) have been proposed for assessment of data-poor fish stocks. It is likely that RPs will need to be tuned for fish with 'unusual' life history traits such as diadromy. Long-term records of the size-distribution of the catch in the rod fishery, and in a fisheries-independent trapping programme are available for sea trout *Salmo trutta* stocks from the River Dee (Wales, UK). These data were used to estimate a length-based harvest rate (*LHR*) and a suite of LBIs for the fishery. Appropriate RPs (with uncertainty) were derived for length-based assessment of sea trout. The LBIs and a decision tree suggest that the stock is likely to be sustainably exploited with regard to length-based and a spawner biomass RP. Increasing the overall harvest rate would result in a greater proportion of rare very large sea trout being taken by anglers. Appropriate length-based RPs for sea trout differ to those proposed for marine demersal species. Expected values for the proportion of megaspawners in the catch are very low, which may be explained by fishing gear (hook and line) selection and the cost of multiple spawning migrations in diadromous fish.

1. Introduction

The life history of diadromous fish species raises particular problems for conservation (e.g., McDowall, 1992, 1999) and many North Atlantic populations have declined dramatically in recent years (Limburg and Waldman, 2009). The demographic and life history characteristics of diadromous fish can be changed by a range of pressures in both freshwater and marine environments (De Groot, 2002; Lassalle et al., 2008). Sea trout is the anadromous form of the brown trout (*Salmo trutta*). It originated as a European species, and is distributed from 42°N to a northern limit at 71°N (Elliott, 1994). Sea trout have historically contributed significantly to the culture and economy of coastal communities, supporting important fisheries and incentivising river conservation (Elliott, 1989). Marked temporal shifts in sea trout population descriptors including size- and age-structure have been observed (e.g., Butler and Walker, 2006; Elliott and Elliott, 2006; Poole et al., 2007; Gargan et al., 2016). These shifts are often associated with strong reductions in abundance, and may reflect important changes in ecological state (McVicar et al., 1993; Poole et al., 1996).

Quantitatively evaluating population state is difficult for most diadromous fish species, except for a few populations that support important commercial fisheries (Limburg and Waldman, 2009). There are very few long-term 'fisheries-independent' monitoring programmes for sea trout (Byrne et al., 2004; Euzenat et al., 2006; Gargan et al., 2016; ICES, 2013, 2017a). Most populations are described only by numbers at size (typically weight) recorded in the angling (rod) catch. Rod catch can reflect population abundance (Thorley et al., 2005), but angling is typically size-selective (e.g., Miranda and Dorr, 2000; Arlinghaus et al., 2008) and catch depends on angler effort that is usually poorly estimated. These factors mean that angling records must be carefully interpreted to capture ecologically important shifts in abundance or population structure. Two ICES workshops, WKTRUTTA (ICES, 2013) and WKTRUTTA2 (ICES, 2017a), have considered options for assessment of sea trout stocks. A new working group (ICES WGTRUTTA) met for the first time in 2017 to initiate development of assessment models and reference points (RPs). The availability of size data from sea trout rod fisheries suggests that length-based approaches may offer a tractable step in this process.

Length-Based Indicators (LBIs) are assumed to reflect size-selective fishing pressure (Rochet and Trenkel, 2003; Froese, 2004; Shin et al., 2005), which can operate at fine spatial scales (de Castro et al., 2015). These indicators may also capture other processes, e.g., sea lice

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infestation of sea trout (Gargan et al., 2016), that can curtail fish population size-distribution. Froese (2004) suggested a 'simple' set of three LBIs: P_{mat} – the proportion of fish in the catch that are larger than length at maturity (L_{mat}), P_{opt} – the proportion of fish larger than optimal harvest length (L_{opt}), and P_{mega} – the proportion of fish larger than L_{opt} + 10%. A simulation study by Cope and Punt (2009) showed that these indicators are not always sufficient to ensure protection from overfishing, and presented a decision tree for identifying and incorporating fishery size-selection in the use of LBIs for assessing stock status. Prince et al. (2011) proposed a harvest rule based on combining CPUE indices with size-based indicators of Spawner Potential Ratio (SPR). SPR is the proportion of the un-fished reproductive potential left at any given level of fishing pressure and is commonly used to set fisheries RPs. The application of SPR has been integrated into the length-based (LB-SPR) method of Hordyk et al. (2015a,b). LB-SPR uses maximum likelihood methods to find the values of relative fishing mortality (F/M) and selectivity-at-length that minimize the difference between the observed and the expected length composition of the catch, and calculates the resulting SPR. The LB-SPR method is an attractive option for sea trout stock assessment, but unfortunately it can currently strongly underestimate SPR for fisheries with dome-shaped selectivity (Hordyk et al., 2015a), the pattern commonly shown for hook-and-line gears.

A more 'basic' potential approach is the use of model-free multi-indicator frameworks that capture different aspects of population dynamics and provide a multi-faceted picture of state (e.g., McDonald et al., 2017). The ICES Workshop on the 'Development of Quantitative Assessment Methodologies based on Life-history Traits, Exploitation Characteristics and other Relevant Parameters for Data-limited Stocks'(WKLIFE V) selected a set of LBIs to screen the length composition of catches and classify given stocks according to conservation and sustainability, yield optimization and Maximum Sustainable Yield (MSY) considerations (ICES, 2015).The WKLIFE LBIs are calculated from the size-distribution of survey or catch data. Each LBI comprises the ratio of a measured length statistic and a corresponding exploitation or life history threshold (Table 1). A traffic light approach (e.g., Caddy et al., 2005) is then used to compare LBI estimates to a RP at which a relevant conservation, yield and/or MSY 'property' is achieved (Table 1). The suite of indicator outputs is considered holistically to provide an 'overall perception' of stock status.

This study used rod and trap catch time series from the River Dee (Wales, UK) to estimate a length-based harvest rate (HR) and a suite of LBIs for sea trout. An empirical method was used to derive appropriate RPs (with uncertainty) for stock assessment of this fish. The Cope and Punt (2009) decision tree was then applied as a complementary approach to identify the likely selectivity pattern in the Dee rod fishery and to make the link to assessing state relative to a spawner biomass RP.

2. Methods

The RPs initially proposed for P_{mat}, P_{opt} and P_{mega} (Froese, 2004) were derived primarily from understanding of the biology and exploitation of demersal teleost fish stocks. The principles were that (a) all fish should spawn at least once (see Myers and Mertz, 1998, for analysis), i.e., P_{mat} in the catch should be ≈1.0, (b) all fish caught should be within 10% of L_{opt} ($P_{opt} \approx 1$), and (c) no fish larger than L_{mega} should be caught and P_{mega} in the population should be at least 30%. It is possible that these RPs will need to be adjusted for fishes with 'unusual' life history, e.g., elasmobranchs (ICES, 2017b) and diadromous species. Spawning migrations are extremely demanding, e.g., Atlantic salmon can use around 60–70% of their body energy reserves during the river phase of migration (Jonsson et al., 1997). Few diadromous individuals may survive to achieve multiple spawning events, e.g., 10 of 25 tagged sea trout migrating upstream died in the river (Aarestrup and Jepsen, 1998). Only about 7.5% of the Dee sea trout run (1991–1995) comprised fish that had spawned once previously, while about 1.6% had spawned twice previously (Davidson et al., 2007).

Selecting appropriate length-based RPs for a given species/stock requires understanding of the size-distribution of a corresponding healthy population, and also of the selection characteristics of the fishery from which stock assessment data will be collected. LBIs calculated from a fishery sample must be related to RPs that represent *expected* indicator values in a sample selected in a similar way from a 'healthy stock'. Equilibrium size-distributions (describing a healthy stock) can be obtained through population simulations (e.g., Cope and Punt, 2009; Babcock et al., 2013) or potentially using empirical data. Empirical approaches offer advantages in the case of sea trout. It is challenging to parameterise a life-history model for this fish because it is typically part of a *Salmo trutta* complex comprising a migratory and non-migratory component with differing size-distributions, behaviour and demography, and unknown partitioning of recruits between components. Sea trout fishing mortality (F) on the Dee is ≈0.03 (Shields et al., 2006). Sustained low F, stable annual catches and the continued presence of some very large individuals suggest that this population may be minimally exploited and have a healthy demographic structure. As such, the population described by the annual trap data (fisheries-independent and non-selective) may be considered close to equilibrium and a pragmatic alternative to the complex task of simulating a sea trout population.

This study presents an empirical approach to deriving RPs, using the Dee trapping programme to provide an approximate size-based census of the annual sea trout run prior to any angler catch. Pairing these trap data with subsequent angling records allows a size-based angling HR to be estimated. The Dee sea trout trap and rod catch data were used to:

- Derive an empirical length-based harvest rate *LHR* for the rod catch.
- Apply this *LHR* as a selection curve to the observed total sea trout run (trap data) in each year to predict the size-distribution of the angler catch.
- Calculate LBIs with uncertainty from annual predicted rod catch size-distributions.
- Use these predicted LBI ranges as assessment RPs, i.e., 'expected values' for LBIs calculated for rod catch from a sea trout population in good state.

Table 1
Derivation of LBIs as applied to sea trout in the River Dee (Wales, UK). Current RP are the reference points provisionally suggested by WKLIFE V (ICES, 2015) and Froese (2004). Table adapted from ICES (2015).

Statistic	Definition	Threshold	Indicator	Current RP	Property
$L_{max5\%}$	Mean length of largest 5%	L_{inf}	$L_{max5\%}/L_{inf}$	> 0.8	Conservation of large individuals
$L_{95\%}$	95th percentile of length	L_{inf}	$L_{95\%}/L_{inf}$	> 0.8	
P_{mega}	Proportion of individuals above L_{opt} + 10%	0.3–0.4	P_{mega}	> 0.3	
$L_{25\%}$	25th percentile of length distribution	L_{mat}	$L_{25\%}/L_{mat}$	> 0.3	Conservation of immature individuals
L_{mean}	Mean length of individuals larger than L_c	L_{mat}	L_{mean}/L_{mat}	> 1	
L_c	Length at first catch (length at 50% of mode)	L_{mat}	L_c/L_{mat}	> 1	
L_{mean}	Mean length of individuals larger than L_c	$L_{opt} = 2/3L_{inf}$	L_{mean}/L_{opt}	≈1	Optimal yield
L_{mean}	Mean length of individuals larger than L_c	$LF = M = (0.75L_c + 0.25L_{inf})$	$L_{mean}/LF = M$	≈1	MSY