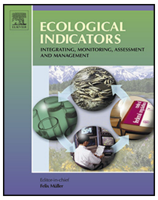
Ecological Indicators 72 (2017) 194–202

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind



Indicators of the 'wild seafood' provisioning ecosystem service based on the surplus production of commercial fish stocks

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ARTICLE INFO

Article history:
Received 25 April 2016
Received in revised form 2 August 2016
Accepted 3 August 2016

Keywords:
Ecosystem services
Seafood provisioning
Sustainable exploitation
Fisheries management
Spawning stock biomass
Fishing mortality

ABSTRACT

The 'Wild Seafood' Provisioning Service (WSPS), on which commercial fisheries rely, is probably one of the best studied marine ecosystem services due to its economic relevance and because extensive information sources exist for assessment purposes. Yet, the indicators often proposed are not suitable to describe the capacity of the ecosystem to deliver the WSPS. Therefore this study proposes surplus production (SP), a well-established concept in fisheries science, as the basis to calculate the capacity of marine ecosystems to provide the WSPS. SP is defined as the difference between stock production (through recruitment and body growth) and losses through natural mortality. This is, therefore, the production of the stock that could be harvested sustainably without decreasing the biomass. To assess the sustainability of the exploitation of the WSPS we also developed an indicator for this based on SP and compared it to existing fisheries management indicators. When both SP-based indicators showed a decreasing trend, contrasting with an increasing trend in the existing fisheries management indicators, the calculation of the SP-based indicators was scrutinized revealing that the weighting of the stocks into an aggregated indicator, strongly determines the indicator values, even up to the point that the trend is reversed. The aggregated indicators based on SP-weighted stocks can be considered complementary to existing fisheries management indicators as the former accurately reflect the capacity of the commercial fish to provide the WSPS and the sustainability of the exploitation of this service. In contrast the existing fisheries management indicators primarily reflect the performance of management towards achieving fisheries-specific policy goals.

1. Introduction

Ecosystem services are the final outputs or products from ecosystems that are directly consumed, used (actively or passively) or enjoyed by people (Fisher et al., 2009; Haines-Young and Potschin, 2013; Maes et al., 2013). Marine ecosystem services include provisioning services, such as wild seafood including fish and shellfish specified as "Nutrition" from "Wild animals and their outputs" in the Common International Classification of Ecosystem Services (CICES); regulation and maintenance services (such as the sea's ability to absorb greenhouse gases); and cultural services (such as the availability of charismatic marine species to observe or to research). We get many benefits from these services such as nutrition, climate regulation and recreation.

The "ecosystem services" concept is essentially anthropocentric because, even though ecosystem characteristics, including structures, processes and functions, have the potential to deliver services (i.e. service "supply"), these only become services if there are people who directly utilise and thus benefit from them (i.e. service "demand") (Fisher et al., 2009; Haines-Young and Potschin, 2013; Maes et al., 2013). This concept, however, can be used as a 'common language' to structure our thinking on the complex relationship between ecosystems and socio-technical systems, which is required for the conservation and best management of these ecosystem characteristics to support the sustained delivery of the services on which human well-being depends. In the ecosystem services 'cascade' model (de Groot et al., 2010; Haines-Young and Potschin, 2010; Maes et al., 2013), adopted by Liquete et al. (2013) for a review of marine and coastal ecosystem services assessments, the above-mentioned ecosystem characteristics underpin the CAPACITY of an ecosystem to provide services, where the functions that ultimately contribute to human well-being cause the FLOW of ecosystem services, and these, in turn, deliver societal

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http://dx.doi.org/10.1016/j.ecolind.2016.08.003

BENEFITS. Service benefits can then be expressed in monetary (i.e. for the fishers) or alternative values (e.g. nutritional for those eating the fish). This conceptual framework can, therefore, be used to structure the indicators or metrics required for an assessment that supports informed management decisions to enhance human well-being. The Liquete et al. (2013) review of marine and coastal ecosystem services showed that the few studies that deal with the assessment of marine ecosystem services have mainly focused on the 'Wild Seafood' Provisioning Service (WSPS), involving fisheries, probably due to its economic relevance and the existence of market prices to value it. According to this review, some of the most meaningful indicators of this service include: abundance or biomass of commercial marine living resources (i.e. CAPACITY), catches or landings (i.e. FLOW) and income from fisheries (i.e. BENEFIT). In this paper, we consider several of these indicators together with two newly developed indicators centred around surplus production to assess their performance in describing the WSPS and its exploitation by fisheries.

The abundance or biomass indicators proposed to assess the WSPS can be considered to represent the ecosystem capacity as, theoretically, all the biomass can be harvested. However, in doing so, the ability of the resource to generate more harvestable biomass through recruitment and/or growth may be compromised. As such it should be considered a "non-renewable resource with a renewable flow of services" (Barbier, 2012). Current fisheries management aims specifically to conserve this ability, which is effectively captured in one of the two indicators commonly used to report the status of commercial fish species, i.e. Spawning Stock Biomass (SSB), representing the amount of biomass of a fish stock above a certain age/size that is considered mature and thus contributing to recruitment (Myers and Barrowman, 1996). For a good capacity indicator we should distinguish between the part of the resource that can be sustainably harvested and the part required to sustain next year's recruitment. Only the former truly reflects the current fish resource's potential for WSPS delivery. We propose surplus production (SP), a well-established concept in fisheries science (Russell, 1931), as the basis to calculate such capacity indicator(s) for the WSPS.

Surplus production is defined as the difference between stock production (through recruitment and body growth) and losses through natural mortality. This is the production of the stock that could be harvested without decreasing the biomass, i.e. if removals can be replaced by stock production each year, the fishery is sustainable (Graham, 1935). Fished populations are more dynamic than unfished populations, with a higher turnover of individual fish as the older fish are replaced by younger, faster growing fish. The environment of fish is very rarely static with conditions in the aquatic environment varying substantially over time. This varying environment interacts with the complex biological processes affecting surplus production levels through variability in growth rates, recruitment, and natural mortality rates. Surplus production, therefore, appears to be the best indicator of the capacity of the fish stock to deliver the WSPS. Hence, in this study we explore two SP-based indicators to describe the supply-side of the WSPS and we assess their suitability to inform ecosystem-based fisheries management towards a sustained delivery of this service.

Fish catches or landings (as proposed by Maes et al., 2013) are indicators associated with the flow of the WSPS. This flow is determined by a highly selective fishing activity reflecting, e.g., quota allowances, which is why these indicators may not show the full potential of the ecosystem to provide the service (Hattam et al., 2015), nor whether this provision is sustainable. Moreover, fishing activities and landings do not necessarily reflect any accompanying decline in fish stocks, but rather may just reflect changes in human preferences (Hattam et al., 2015) or societal decisions aimed at, e.g., achieving conservation targets. As such, the most common fisheries indicator, i.e. landings, which is catch minus the discards, relates to the "demand" side for ecosystem services assessment (i.e. by representing how much of the flow is actually consumed, used or enjoyed by people) rather than to the "supply" side, i.e. to the ecosystem's potential for service delivery, for which we propose SP as the preferred indicator. The ratio of SP/landings, however, reflects to what extent the exploitation of the ecosystem's capacity is sustainable. This ratio can be used to comprehensively inform policy aimed at sustainable exploitation of the marine resources as well as a sustained delivery of ecosystem services (European Commission, 2011) on the performance of fisheries management. As such, we will explore in this paper if this ratio can provide anything that complements the information provided by existing fisheries management indicators.

2. Material & methods

This study introduces three potential indicators for the WSPS: surplus production (*SP*) representing the capacity of the ecosystem to deliver the service, and two metrics reflecting the sustainability of the exploitation of the food provisioning capacity (*SFP*) and management performance to achieve this sustainability (*MPS*), but which differ in how they are calculated across the whole resource as they represent different perspectives (respectively food provisioning perspective and management performance perspective). A simple way to calculate surplus production for a single stock, requiring any type of assessment model output, is to start from the basic equation that calculates the change in fish stock biomass:

$$B_{stock,y+1} - B_{stock,y} = (recruitment + body\ growth) - natural\ mortality - C_{stock,y}$$

and rearrange this into

$$SP_{stock,y} = (B_{stock,y+1} - B_{stock,y}) + C_{stock,y}.$$

Where $B_{stock,y}$ represents the biomass of a specific stock in year *y*, '*recruitment*', '*body growth*' and '*natural mortality*' are components of net stock production due to natural processes, i.e. *SP*, and '*catch*' ($C_{stock,y}$) represents the impact of the fishery as removals from the stock. In practice, the data often only represents the landings (*L*), which is catch minus the discards.

Total SP for a specific year *y* in any marine ecosystem/region is then the aggregate across all fish stocks in that ecosystem/region.

$$SP_y = \sum_{i=stock}^{n} SP_{stock,y}$$

And the two metrics that reflect the sustainability of the exploitation of the food provisioning capacity:

$$SFP_y = \frac{SP_y}{\sum_{i=stock}^{n} L_{stock,y}}$$

$$MPS_y = \frac{\sum_{i=stock}^{n} SP_{stock,y}/L_{stock,y}}{n}$$

which only differ in the method of aggregation across stocks, i.e. for SFP each stock is weighted by their contribution to SP, while MPS is based on an aggregation where every stock is equally important.

In addition we present three indicators which are based on existing fisheries management indicators and are often used to inform policy on what are considered the main aspects of stock status but are now calculated to reflect the status of all marine species that contribute to the WSPS, i.e. all commercial (shell)fish stocks. To that end the following aggregate indicators (i.e. across stocks) are calculated based on the indicator values in relation to their policy goals:

- Sustainable exploitation (SE): Sustainably exploited stocks are stocks for which fishing mortality (F) is at or below levels that deliver Maximum Sustainable Yield (MSY), i.e. $F \leq F_{MSY}$. This is reflected in the indicator calculated per year (y) as

$$SE_y = \frac{\sum_{i=stock}^{n}(F_y/F_{MSY})_{stock}}{n}$$

- Reproductive capacity (RC): In the International Council for the Exploration of the Seas (ICES) area, which effectively implies the North East Atlantic and Baltic sea, a stock is assumed to have sufficient reproductive capacity with a high degree of confidence if spawning stock biomass is above the lowest level which can produce MSY, i.e. MSY $B_{trigger}$, but in practice is set as the border of safe biological limits (B_{pa}). Thus SSB > MSY $B_{trigger}$. This is reflected in the indicator calculated per year as

$$RC_y = \frac{\sum_{i=stock}^{n}(RC_y/MSYB_{trigger})_{stock}}{n}$$

- The main objective of the European Union (EU) Marine Strategy Framework Directive (MSFD) is to achieve 'Good Environmental Status (GES)' (European Commission, 2008): A stock is in GES if both of the above criteria are fulfilled. The indicator is calculated for a particular suite of species (i.e. per marine region or in this case all ICES stocks) reflecting for each year the proportion of stocks that are in GES:

$$GES_y = \sum_{i=stock}^{n}(SE_{stock,y} \leq 1 and RC_{stock,y} \geq 1)/n$$

The calculation of the WSPS metrics is based on all EU commercial fish stocks in the ICES stock database for which the data required to calculate the WSPS metrics were available and which allowed comparison with the existing indicators used in fisheries management, i.e. fishing mortality (F) and Spawning Stock Biomass (SSB). The ICES Stock database has been downloaded from http://www.ices.dk/marine-data/tools/Pages/stock-assessment-graphs.aspx. Official citation: "ICES Stock Database, Extraction date: 2015/04/01 of all stocks 2015. ICES, Copenhagen". This downloaded ICES Stock database consists of 80 stocks providing information by stock and year on a number of variables. For three stocks (i.e. rng-5b67, anb-8c9a and pan-sknd, see Table 1) we suspected the reported biomass not to be absolute biomass as is required for the analysis and these were therefore excluded from the analysis.

Even though related, the metrics and indicators used in these analyses all have slightly different data requirements. This, combined with the fact that the stocks may differ in the availability of data, causes variation in the suite of stocks on which the calculation of the specific indicators or metrics is based (Table 1). All stocks for which absolute biomass and landings estimates are available (i.e. stocks for which it is possible to calculate SP, SFP and MPS), are included in the analysis. For the Norway pout stock in the North Sea and Skagerrak only the autumn assessment (i.e. nop-34-oct) was used as, opposed to the summer assessment, only this assessment allowed calculation of the SP.

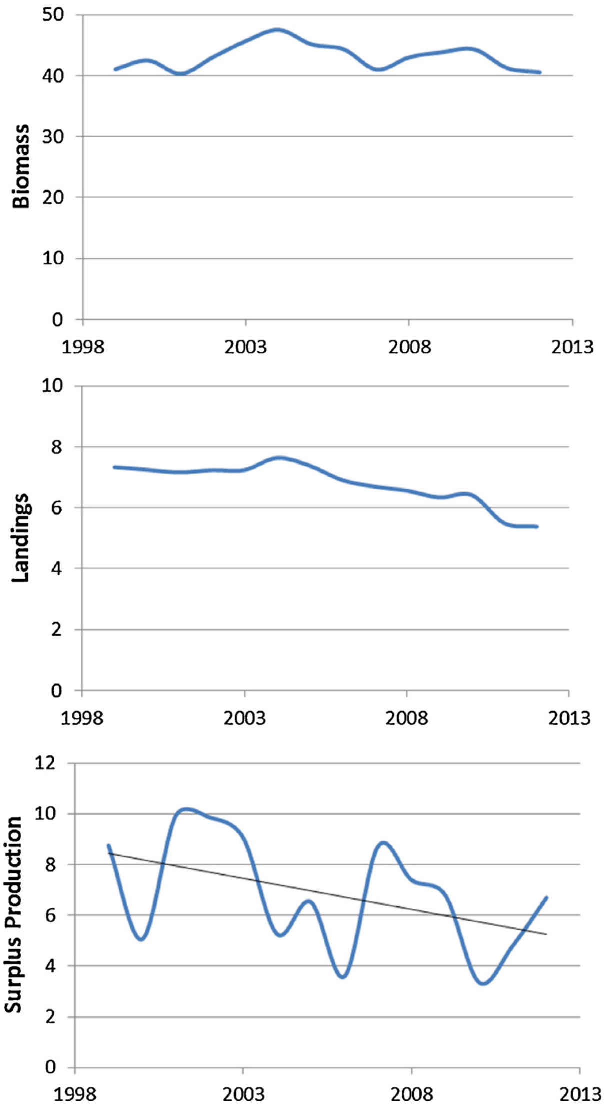

Fig. 1. 'Wild Seafood' Provisioning Service (WSPS) metrics. Units are in million tonnes. For stocks included to calculate the metrics see Table 1, SP column.

Ideally any assessment of the WSPS should be comprehensive in that it should be based on all marine species contributing to this service, i.e. all types of seafood people consume. In reality, only part of these marine species are covered by adequate data and this proportion is often increasing over time. Therefore, a balance needs to be struck in such assessments between the number of species (or actually stocks as most data are stock-based) to include and the length of the time period that can be covered. This is reflected in the results where the calculation of the metrics and indicators is based on the period 1999–2012 and includes 50 stocks making up most, i.e. 72%, of the total European (EU) landings but representing only the North-east Atlantic and Baltic sea, not the Mediterranean and Black sea.

3. Results

Based on the information in the ICES stocks database, we calculated two indicators often used to report on the WSPS, i.e. biomass and landings, together with one of our proposed indicators: Surplus Production (SP) (Fig. 1). This shows that Biomass remains fairly stable over time while the Landings are gradually decreasing. In contrast, the SP shows considerable variability over time but also, at least over the time period considered, a decreasing trend. The supply of the WSPS thus appears to be declining albeit with considerable variability.

Table 1
Overview of stocks available in ICES Stock Database 01-04-2015. (source: http://www.ices.dk/marine-data/tools/Pages/stock-assessment-graphs.aspx). Assessment biomass is reported in Absolute (A) or Relative (R) terms, stocks with * excluded because biomass was suspected not to be absolute. Stocks with + required the information to allow calculation of Surplus Production (SP), Sustainable exploitation (SE), Reproductive Capacity (RC) or Good Environmental Status (GES). Only stocks in bold were included in the calculations of the indices.

Fishstock	Stock description	Biomass	SP	SE	RC	GES
anb-8c9a	Black-bellied anglerfish (Lophius budegassa) in Divisions VIIIc and IXa	A*				
ane-bisc	**Anchovy (Engraulis encrasicolus) in Subarea VIII**	**A**	+			
anp-8c9a	**White anglerfish (Lophius piscatorius) in Divisions VIIIc and IXa**	**A**	+	+		
bli-5b67	Blue ling (Molva dypterygia) in Subareas VI–VII and Division Vb	A		+		
boc-nea	Boarfish (Capros aper) in Subareas VI-VIII	R				
bss-47	**Seabass (Dicentrarchus labrax) in Divisions IVb and c, VIIa and VIId–h**	**A**	+	+		
cap-icel	Capelin (Mallotus villosus) in Subareas V and XIV and Division IIa west of 5° W	A				
cod-2224	**Cod (Gadus morhua) in Subdivisions 22–24**	**A**	+	+	+	+
cod-347d	**Cod (Gadus morhua) in Subarea IV and Divisions VIId and IIIa West**	**A**	+	+	+	+
cod-7-ek	**Cod (Gadus morhua) in Divisions VIIe-k**	**A**	+	+	+	+
cod-arct	**Cod (Gadus morhua) in Subareas I and II**	**A**	+	+	+	+
cod-farp	**Cod (Gadus morhua) in Subdivision Vb1**	**A**	+	+	+	+
cod-iceg	**Cod (Gadus morhua) in Division Va**	**A**	+			
cod-iris	**Cod (Gadus morhua) in Division VIIa**	**A**	+	+	+	+
cod-scow	**Cod (Gadus morhua) in Division VIa**	**A**	+	+	+	+
had-346a	**Haddock in Subarea IV and Divisions IIIa West and VIa**	**A**	+	+	+	+
had-7b–k	**Haddock in Divisions VIIb,c,e-k**	**A**	+	+	+	+
had-arct	**Haddock in Subareas I and II**	**A**	+	+		
had-faro	Haddock in Division Vb	A		+	+	+
had-iceg	Haddock in Division Va	A			+	
had-iris	Haddock in Division VIIa	R				
had-rock	**Haddock in Division VIb**	**A**	+	+	+	+
her-2532	**Herring in Subdivisions 25–29 (excluding Gulf of Riga) and 32**	**A**	+	+	+	+
her-30	**Herring in Subdivision 30**	**A**	+	+	+	+
her-31	Herring in Subdivision 31	R				
her-3a22	**Herring in Division IIIa and Subdivisions 22–24**	**A**	+	+	+	+
her-47d3	**Herring in Subarea IV and Divisions IIIa and VIId**	**A**	+	+		
her-irls	Herring in Division VIIa South of 52° 30′ N and VIIg,h,j,k	A		+	+	+
her-irlw	Herring in Divisions VIa (South) and VIIb,c	R				
her-nirs	**Herring in Division VIIa North of 52° 30′ N**	**A**	+	+	+	+
her-noss	**Herring in Subareas I, II, V and Divisions IVa and XIVa**	**A**	+	+	+	+
her-riga	**Herring in Subdivision 28.1**	**A**	+	+	+	+
her-vasu	**Herring in Division Va**	**A**	+	+	+	+
her-vian	**Herring in Division VIa (North)**	**A**	+	+		
hke-nrtn	**Hake in Division IIIa, Subareas IV, VI and VII and Divisions VIIIa,b,d**	**A**	+	+	+	+
hke-soth	Hake in Division VIIIc and IXa	A		+		
hom-soth	Horse mackerel (Trachurus trachurus) in Division IXa	A		+		
hom-west	**Horse mackerel (Trachurus trachurus) in Divisions IIa, IVa, Vb, VIa, VIIa–c, e–k, VIII**	**A**	+	+	+	+
lin-icel	**Ling (Molva molva) in Division Va**	**A**	+	+	+	+
mac-nea	**Mackerel in the Northeast Atlantic**	**A**	+	+		
mgb-8c9a	Four-spot megrim (Lepidorhombus boscii) in Divisions VIIIc and IXa	A		+	+	+
mgw-78	Megrim (Lepidorhombus whiffiagonis) in Divisions VIIb–k and VIIIa,b,d	R				
mgw-8c9a	Megrim (Lepidorhombus whiffiagonis) in Divisions VIIIc and IXa	A		+	+	+
nop-34-june	Norway Pout in Subarea IV and IIIa – Summer assessment	A				
nop-34-oct	**Norway Pout in Subarea IV and IIIa – Autumn assessment**	**A**	+		+	
pan-barn	Northern shrimp (Pandalus borealis) in Subareas I and II (Barents Sea)	A		+	+	+
pan-sknd	Northern shrimp (Pandalus borealis) in Divisions IIIa West and IVa East	A*				
ple-2123	Plaice in Subdivisions 21, 22, and 23	R				
ple-7h–k	Plaice in Divisions VIIh–k	R				
ple-celt	Plaice in Divisions VIIf,g	R				
ple-eche	Plaice in Division VIId	R				
ple-echw	**Plaice in Division VIIe**	**A**	+	+	+	+
ple-iris	Plaice in Division VIIa	R				
ple-nsea	Plaice Subarea IV	A		+	+	+
rng-5b67	Roundnose grenadier (Coryphaenoides rupenstris) in Subareas VI and VII. and Divisons Vb and XIIb	A*				
sai-3a46	**Saithe in Subarea IV (North Sea) Division IIIa West (Skagerrak) and Subarea VI**	**A**	+	+	+	+
sai-arct	**Saithe in Subareas I and II**	**A**	+			
sai-faro	**Saithe in Division Vb**	**A**	+	+	+	+
sai-icel	Saithe in Division Va	A			+	
san-ns1	**Sandeel in the Dogger Bank area (SA 1)**	**A**	+		+	
san-ns2	**Sandeel in the South Eastern North Sea (SA 2)**	**A**	+		+	
san-ns3	**Sandeel in the Central Eastern North Sea (SA 3)**	**A**	+		+	
sar-soth	**Sardine in Divisions VIIIc and IXa**	**A**	+			
smr-5614	**Golden Redfish (Sebastes norvegicus) in Subareas V, VI, XII and XIV**	**A**	+			
sol-7h–k	Sole in Divisions VIIh-k	R				
sol-bisc	**Sole in Divisions VIIIa,b**	**A**	+	+	+	+
sol-celt	**Sole in Divisions VIIf,g**	**A**	+	+	+	+
sol-eche	**Sole in Division VIId**	**A**	+	+	+	+
sol-echw	**Sole in Division VIIe**	**A**	+	+	+	+
sol-iris	**Sole in Division VIIa**	**A**	+	+	+	+
sol-kask	Sole in Division IIIa and Subdivisions 22–24	A		+	+	+
sol-nsea	Sole in Subarea IV	A		+	+	+

Table 1 (*Continued*)

Fishstock	Stock description	Biomass	SP	SE	RC	GES
spr-2232	**Sprat in Subdivisions 22–32**	**A**	+	+	+	+
spr-nsea	**Sprat in Subarea IV**	**A**	+	+	+	+
tur-nsea	**Turbot in Subarea IV**	**R**				
usk-icel	**Tusk in Division Va and Subarea XIV**	**A**	+	+		
whb-comb	**Blue whiting in Subareas I–IX, XII and XIV**	**A**	+	+	+	+
whg-47d	**Whiting Subarea IV (North Sea) and Division VIId**	**A**	+			
whg-7e–k	**Whiting in Division VIIe–k**	**A**	+	+	+	+
whg-scow	**Whiting in Division VIa**	**A**	+			

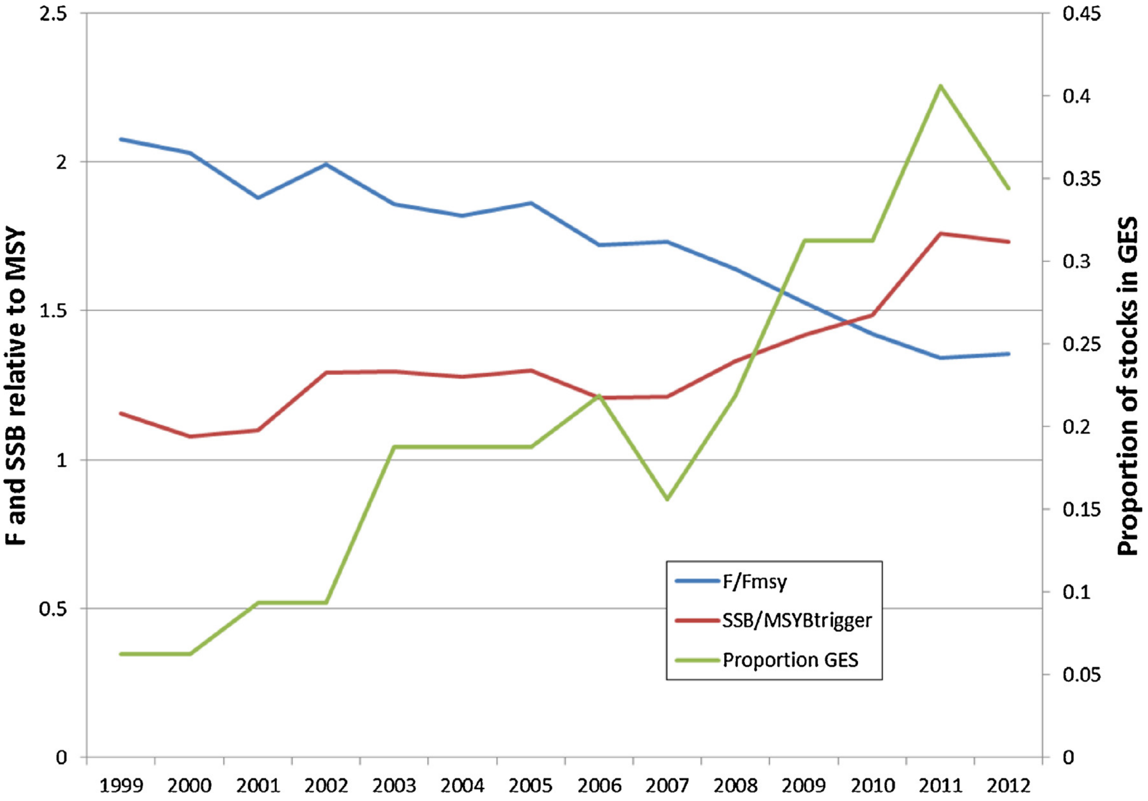

Fig. 2. Existing European fisheries management indicators: F/F_{MSY} (representing Sustainable exploitation, SE), SSB/MSY $B_{trigger}$ (representing Reproductive Capacity RC) and Proportion of stocks in GES (i.e. fulfilling both $F \leq F_{MSY}$ and SSB ≥ MSY $B_{trigger}$). For stocks see Table 1.

The existing fisheries management indicators often used to inform policy on the status of the commercial fish stocks and exploitation levels, however, convey a different message. Fig. 2 shows that overall the levels of exploitation (F) are decreasing, although with F/F_{MSY} still above 1 overall exploitation is above the upper limit that would achieve the policy goal of MSY. As a consequence, the stocks are recovering and the SSB is increasing to well above MSY $B_{trigger}$, the lower limit that can produce MSY, so that it can be considered within the normal range of fluctuations in SSB should the stocks be exploited at MSY. The decrease in F and subsequent increase in SSB has resulted in an increase of the proportion of stocks in GES so that in the last year close to 40% of the stocks are in GES. The status of the resource on which the WSPS depends thus appears to be improving.

These inverse trends of a decreasing supply of the WSPS while the status of the resource is improving appear difficult to reconcile as both are supposed to provide information on the sustainable provisioning of seafood. This potential contradiction was further explored through comparing the two metrics on the sustainability of the exploitation of the food provisioning capacity, i.e. SFP and MPS, in which the stock-based information is aggregated differently in order to represent different perspectives (Fig. 3). The perspective reflected by the decreasing SFP is the sustainability of the overall exploitation of the whole resource in terms of its food provisioning capacity based on an aggregation where the importance of each stock is weighted by their contribution to the food provisioning capacity SP. The perspective reflected by the increasing MPS would be the performance of fisheries management in achieving a sustainable exploitation for each stock separately, which is based on an aggregation where every stock is equally important. This is expected to be strongly aligned to the number of stocks in GES. Thus while fisheries management is increasingly more successful in terms of the number of stocks in GES, this is not (or less so) the case for the food provisioning capacity (reflected by SP) or its overall exploitation (reflected by SFP). This is because fisheries management has often performed poorly on the stocks that contribute most to the WSPS resulting in landings exceeding SP for those stocks. This is illustrated in Fig. 4 showing the relative contribution of the different stocks to SP (and hence SFP), which is far from equal. Few stocks, i.e. blue whiting (whb-comb), mackerel (macnea), two widely distributed species, Norwegian Spring Spawning Herring (her-noss) and North sea herring (her-47d3), Arctic cod (cod-arct) and Baltic sea sprat (spr-2232), make up more than two-third of the total European SP. All of these stocks except Arctic cod

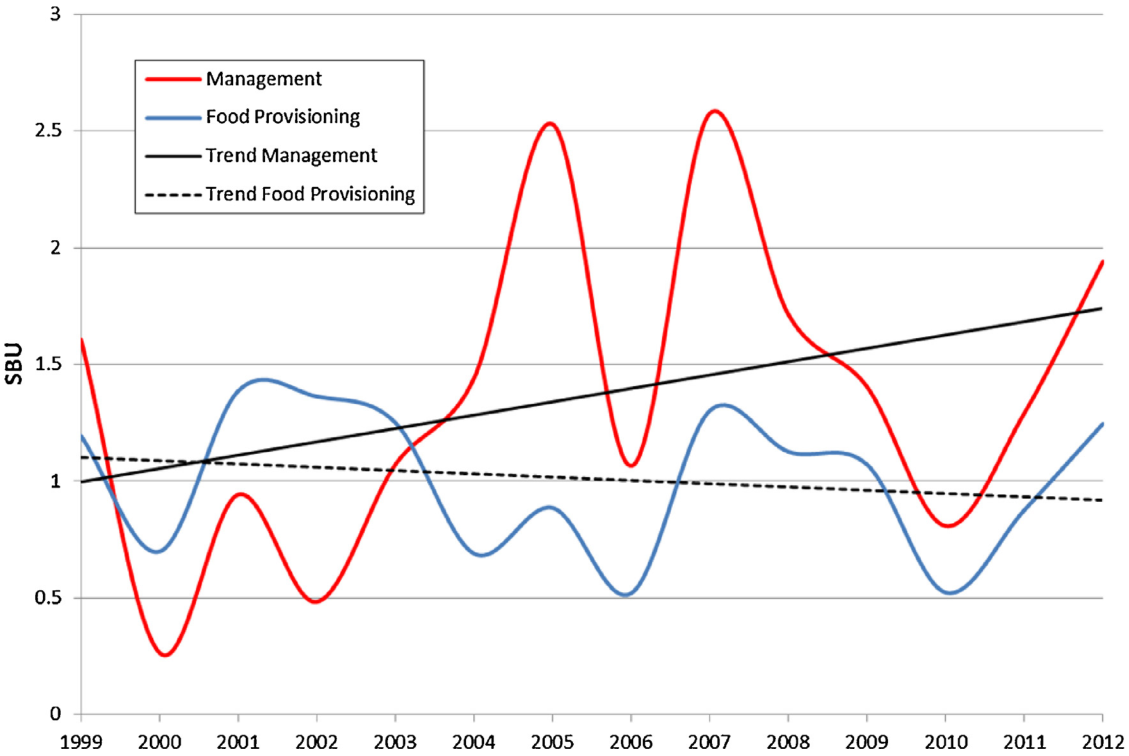

Fig. 3. Two indices reflecting both the sustainability of food provisioning: SFP "Food provisioning" reflects the overall level of exploitation of the service supply and is based on an aggregation where the importance of each stock is weighted by their contribution to Surplus Production, MPS "Management" reflects the performance of management in terms of securing the desired sustainability and is based on an aggregation where every stock is equally important. For stocks see Table 1.

are pelagic species. Three of these stocks (i.e. whb-comb, her-noss and her-47d3) are responsible for the largest changes of SP over time, which are all decreases.

4. Discussion

This study introduces surplus production (SP), a well-established concept in fisheries science, as the basis to calculate the capacity of marine ecosystems to provide the WSPS. The study shows that its values differ markedly from indicators that are currently mostly used to represent the WSPS, i.e. biomass or landings. Moreover, the SP trend over time is the inverse of the current indicators representing the status of the commercial fish. Thus we believe these current indicators are not suitable to represent the WSPS and we propose SP as the most appropriate indicator.

As all the indicators presented in this study (including SP) are calculated from a relatively small subset of all the marine fish (i.e. commercial fish species covered by stock assessments) they could easily be criticised for misrepresenting the capacity of the total marine fish to contribute to the 'Wild Seafood' Provisioning Service (WSPS). However, while this subset only makes up a relatively small component in terms of its contribution to the biomass present in the marine ecosystem, it makes up a key component in terms of its contribution to the actual marine ecosystem WSPS. This because the capacity of the ecosystem, i.e. the possible service 'supply', only becomes a service once it's being used and contributes to human welfare (Fisher et al., 2009; Haines-Young and Potschin, 2013; Maes et al., 2013). Thus, Surplus Production (SP), even if limited to the main commercial fish stocks, is probably the best indicator currently available to describe the capacity of the ecosystem to deliver the WSPS. In addition the SP-based SFP indicator is suitable to inform policy on the performance of fisheries management towards a sustained delivery of the WSPS. Moreover, it is probably a better indicator to inform on the performance of fisheries management in relation to this specific service than aggregates of the conventional fisheries management indicators based on an equal weighting of the stock-based information.

In his 8 fundamental principles of fisheries management, (Cochrane, 2000) noted that the biological production from fish stocks is finite (and hence constrains fisheries' potential yield), and that this biological production is a function of both the stock size and the ecological environment including, for example, nursery areas (Liquete et al., 2016), which may be impacted on by both natural and human-induced changes. This last point highlights the limitations of SSB as an indicator of the capacity to deliver the WSPS. While SSB may include some information on the potential for new recruits, it does not necessarily reflect the productivity of a stock at any given time since it ignores broader environmental conditions. This, in contrast, does not apply to SP, which reflects exactly the biological production available for the WSPS.

The SP shows markedly more variation over time than the indicators that are currently mostly used to represent the WSPS, i.e. biomass or landings (see Fig. 1). This large variation, together with the fact that the SP for the current year is unknown, causes an exploitation aimed at capturing all of the accessible resource surplus to overshoot in one year and undershoot in the other. As a result the stock (i.e. total fish biomass) is expected to change over time, albeit with much less variability than the accessible resource surplus (see Fig. 1). Considering that fish biomass is relatively stable while SP appears to be decreasing with high variability, the productivity (i.e. production per biomass) of at least the main stocks contributing to the SP must be causing this. Large variability in pelagic fish recruitment is frequent (Smith, 1985) and can have a large influence on SP. Additionally, for many stocks recruitment variability follows multi-decadal cycles, often varying independently from fishing mortality, driven by changes in environmental conditions (Rothschild, 2000). Other stocks, such as haddock or horse mackerel in the northeast Atlantic, are char-

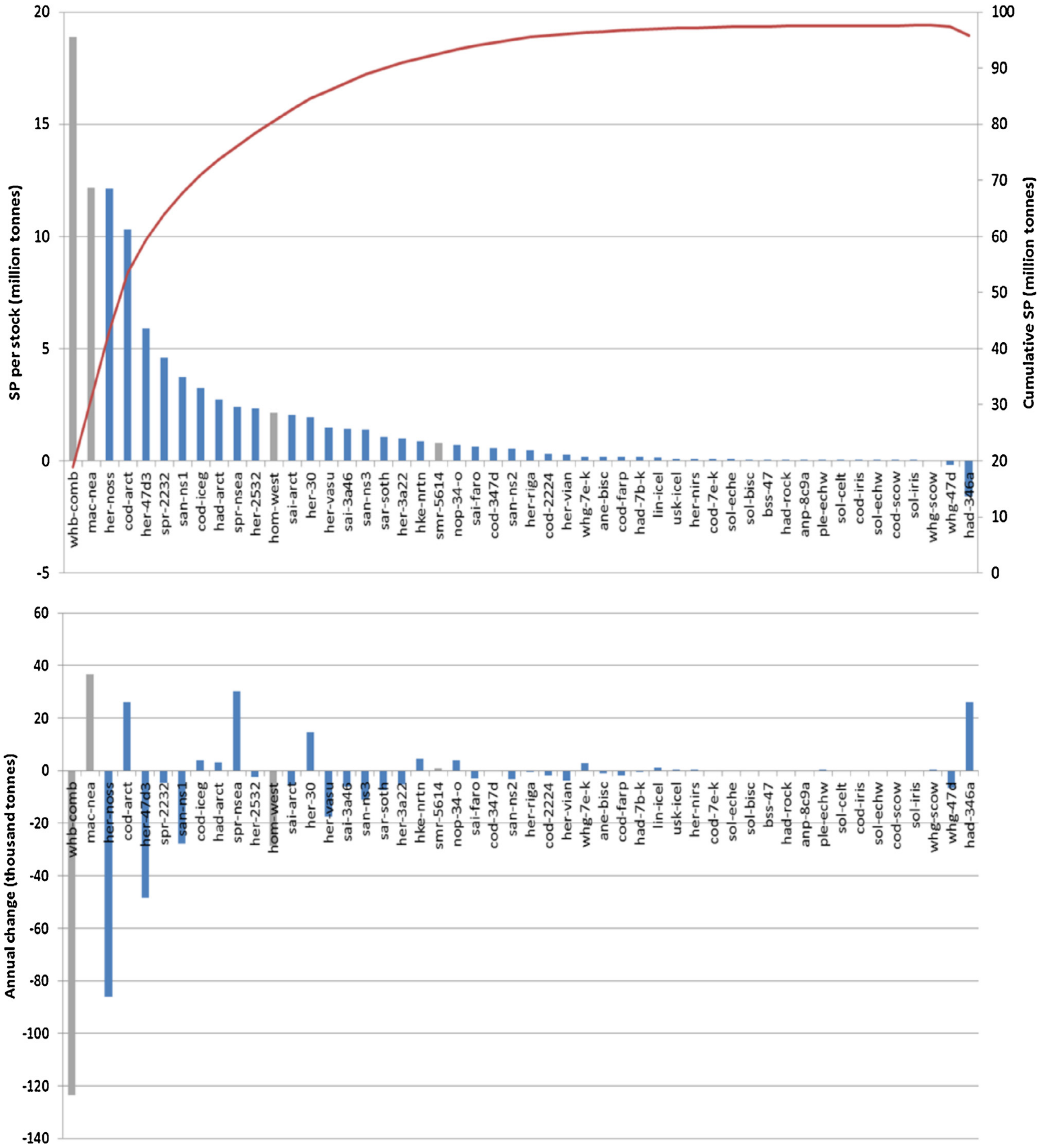

Fig. 4. Surplus production per stock ordered according to the total SP over the study period and the cumulative SP (upper graph) and the mean annual change over time per stock (lower graph). Grey bars indicate migratory, widely distributed stocks occurring in several marine regions. For abbreviations stocks see Table 1.

acterised by occasional large 'spikes' in recruitment, leading to very high productivity in certain years, with periods of low or negative productivity in between. The combination of all these factors leads to the observed high variability in SP, and may also explain its decrease over the time despite sustainable landings. As SP decreases faster than the landings, this results in a decreasing SFP (i.e. the proportion of the SP taken by landings) even to the point (i.e. SFP < 1) that overall landings are bigger than the total SP of commercial fish and, thus, the overall level of exploitation becomes unsustainable. Over the entire period, however, exploitation can be considered sustainable because SFP is above 1.

Although the decreasing trend over time could be cause for alarm, it should not be interpreted as a sign that fisheries management is not succeeding in ascertaining a sustainable exploitation of the commercial fish as appropriate indicators and thresholds already exist for that, but rather as a warning sign that natural processes may be occurring in the respective regional ecosystems that could jeopardize the food provisioning capacity of at least some of the main fish stocks. With 6 out of the total 50 stocks contributing to approximately two-thirds of the food-provisioning capacity (see Fig. 4), this is almost entirely driven by only a few stocks and strongly dependent on the time period considered. Two years of higher productivity of one or more of the main fish stocks and thus increased SP could nullify this downward trend. Hence while a combined index may provide a good overview, examination of the component parts of this index (i.e. the individual stocks) may be necessary to properly interpret the patterns in SP over time.

Hence, SP or any of the existing indicators are probably best suited as "surveillance indicators", which are not supposed to underpin specific management action but rather provide complementary information (including warning signals) that provide a broader and more holistic picture of state, and inform and support policy (Shephard et al., 2015). Pertaining to this, we need to bear in mind that also in the biomass data on which these indicators are based the last (most recent) year will always be the most poorly estimated. This is the inherent difficulty of fisheries management, i.e. never knowing the exact current status, nor what is likely in the immediate future. Catch or landings data may be more accurate, but what that means in terms of fishing mortality and what that level of catch did to the stock (relative to its production) will be uncertain until a few more years of data become available. As with fisheries assessment models, the scaling of these SP indicators may be affected by the availability or quality of discard information. Simply, if the level of discards is not estimated, then SP will be underestimated. In other words, unknown discards are essentially unregistered productivity. From a precautionary perspective, it is safer to underestimate the capacity to provide the WSPS than it is to overestimate it. So while not having information on discards will affect the accuracy of the SP indicators, this does not strongly affect the validity of the indicators. Moreover, uncertainty around the level of standing stock (biomass) is likely to have a greater effect on the accuracy of the estimated SP.

Thus SP is probably appropriate to inform on the performance of fisheries management specifically in relation to the capacity of ecosystem to deliver the WSPS but not suitable to be used as part of the short-term, i.e. annual or even multi-annual, fisheries management. For this latter role, more detailed, relatively data-heavy age-structured models (e.g. virtual population analysis VPA or statistical catch-at-age SCA) are usually applied as they are believed to provide better insights into the impact of current fishing pressure on stock size in relation to policy targets. However, developing full age-disaggregated stock assessment models for all stocks is an unrealistic aim. And while this study showed most of the northern European stocks are covered by such assessment models, this is certainly not the case in many other marine ecosystems or regions. Hence in order to calculate indicators that can be more universally applicable simpler approaches are necessary. Surplus production models have much simpler data requirements than full age-based models with only total catch and effort data being required, though fisheries independent indices can also be included where available. However, since these surplus production models estimate an intrinsic growth rate (that can be likened to a measure of productivity of a stock) that is constant over time (in most cases), but varies depending on the biomass, they may not capture trends in productivity over time due to ecological or environmental factors. The more data-rich, age structured models incorporate time varying growth (through annual weight at age estimates) and recruitment, so are more likely to show appropriate changes in productivity over time and capture the impact of occasional 'spikes' in recruitment that exist in some stocks. However, while surplus production models may not be as suitable, the ability to apply these to data-limited stocks could allow these indicators to be generally applied in regions where less sophisticated data are available than used in this study. Hence SP is more likely to be applied in the data-poor situations than the fisheries management indicators presented in this study.

The calculation and application of SP-based indicators shows that knowledge and research efforts appear not to be proportionally distributed if the aim of fisheries management is to sustainably provide the WSPS. This analysis, for example, shows that a large number of fish species/stocks are assessed that hardly contribute to the WSPS. However, in addition to the perspectives considered in this study, we need to acknowledge there are many other perspectives to compare the research efforts against such as those directed at species with high economic or societal value, or species with specific roles in the foodweb, or simply because each species contributes to biodiversity, a property of the ecosystem which needs to be conserved according to many policy frameworks (European Commission, 2008, 2011).

The different perspectives considered in this study and how these translate into different weightings of the stocks into an aggregated metric which in turn results in very different outcomes of the assessment, stresses the importance to explicitly consider aggregation, a contentious issues in any integrated assessment of marine environmental status (Borja et al., 2014) where lower-level information needs to be aggregated into high-level indicators. In addition, or alternatively, a weighting according to market prices per species could be used to calculate another WSPS metric reflecting their societal value.

Acknowledgements

The work presented in this paper was produced under a European Topic Centre grant agreement with the European Environment Agency (EEA). The opinions expressed in the paper are those of the authors only and do not necessarily reflect the official opinion of the EEA or other European Communities bodies and institutions. The research leading to these results has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no 642317.

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