frontiers
in Marine Science

ORIGINAL RESEARCH
published: 30 June 2017
doi: 10.3389/fmars.2017.00209

Ecological-Economic Fisheries Management Advice—Quantification of Potential Benefits for the Case of the Eastern Baltic COD Fishery

Rudi Voss [1]*, Martin F. Quaas [1], Max T. Stoeven [1], Jörn O. Schmidt [1], Maciej T. Tomczak [2] and Christian Möllmann [3]

[1] Sustainable Fishery, Department of Economics, University of Kiel, Kiel, Germany, [2] Baltic Sea Centre, Stockholm University, Stockholm, Sweden, [3] Center for Earth System Research and Sustainability, Institute for Hydrobiology and Fisheries Science, University of Hamburg, Hamburg, Germany

Fishing is a social and economic activity, and consequently socio-economic considerations are important for resource management. While this is acknowledged in the theory of Ecosystem-Based Management (EBM) and its sector-specific development Ecosystem-Based Fisheries Management (EBFM), currently applied fishery management objectives often ignore economic considerations. Year-to-year management, however, implicitly responds to short-term economic interests, and consequently, regularly resorts to tactical short-term rather than strategic long-term decisions. The aim of this article is to introduce a new way of estimating management advice referred to as an "ecologically-constrained Maximum Economic Yield" (eMEY) strategy, which takes into account ecological criteria as well as short- to medium-term economic costs. We further illustrate what net cost reductions per year are possible applying the eMEY strategy compared with the existing way of setting total allowable catches (TACs). The eMEY approach aims at maximizing the economic benefits for the fishery as well as society (consumers), while safeguarding precautionary stock sizes. Using an age-structured optimization model parameterized for the Eastern Baltic cod case study, we find that application of eMEY advice results in more stability in catch advice. Quantification and visualization of the costs of deviating from eMEY advice offers a transparent basis for evaluating decision-making outcomes. The costs of overfishing are mainly borne by the commercial fishery, while fishing less than optimal is particularly costly for the processing industry and consumers. To foster the uptake of our eMEY approach in current advice given by the International Council for the Exploration of the Sea (ICES) and the EU fishery management system, we suggest an easy-to-implement scheme of providing integrated advice, also accounting for economic considerations.

Keywords: EBFM, Baltic, Cod, profits, consumer

Edited by:
Athanassios C. Tsikliras,
Aristotle University of Thessaloniki,
Greece

Reviewed by:
Fabian Zimmermann,
Norwegian Institute of Marine
Research, Norway
Katrine Soma,
Wageningen University and Research,
Netherlands

***Correspondence:**
Rudi Voss
voss@economics.uni-kiel.de

Specialty section:
This article was submitted to
Marine Fisheries, Aquaculture and
Living Resources,
a section of the journal
Frontiers in Marine Science

Received: *19 January 2017*
Accepted: *16 June 2017*
Published: *30 June 2017*

Citation:
Voss R, Quaas MF, Stoeven MT,
Schmidt JO, Tomczak MT and
Möllmann C (2017)
Ecological-Economic Fisheries
Management Advice—Quantification
of Potential Benefits for the Case of
the Eastern Baltic COD Fishery.
Front. Mar. Sci. 4:209.
doi: 10.3389/fmars.2017.00209

INTRODUCTION

Overfishing is a major challenge to global future sustainable development (United Nations, 2015). It threatens biodiversity as well as food security, and economic, social and cultural values, and thus livelihoods connected to the sea. Accordingly, sustainable use of marine resources has been identified as a global and internationally highly ranked policy goal (United Nations, 1982). Leading documents refer to the Maximum Sustainable Yield (MSY) concept, which should be applied to reach sustainability objectives. While social and economic objectives were explicitly included as constraints in the initial formulations (United Nations, 2002), fisheries management increasingly focused on fish stock size as the only criterion. This can be explained by comparably low data needs as the underlying MSY-concept is mostly based on a biological single-species (in some cases multi-species) perspective to derive management recommendations. Nevertheless, the focus on MSY-based management remains somewhat surprising, as many problems related to it have already been identified in the 1970s (e.g., Larkin, 1977). Major points of criticism include advocating too high yields under environmental variability or change, neglecting species interactions, and absence of any social or economic considerations:

> *Here lies the concept, MSY, It advocated yields too high, And didn't spell out how to slice the pie. We bury it with best of wishes, Especially on behalf of fishes.* Larkin (1977).

Such a restriction in the interpretation of sustainable fishing is, however, in contradiction to Ecosystem-based Fisheries Management (EBFM). EBFM explicitly includes ecosystem as well as social, cultural and economic considerations, and its further development is high on the international science and policy agenda (ICES, 2014b; NOAA, 2015).

After the revision of the EU Common Fisheries Policy in 2013, a first Multi Annual Management Plan (MAP) was developed for the Baltic Sea region, which is supposed to act as a blueprint for other European regions. The Baltic MAP mentions social and economic objectives, but actual management is still based only on criteria to meet reference levels of fishing mortality (F_{MSY}) or stock size, i.e., to reach levels at or above B_{MSY} (the stock biomass to produce maximum sustainable yield; EU, 2013, 2015).

Currently, scientific (ecological) advice on the ecologically and economic important Eastern Baltic cod stock is based on work by the ICES Baltic Fisheries Assessment Working Group (WGBFAS). On a yearly basis, WGBFAS assesses and evaluates stock status and dynamics, and predictions of catch option for the next year are performed. Catch options and advice are drafted and delivered to the EU Commission, which takes the actual catch decision. The Commission is supported in its work by stakeholder input from the Baltic Sea Advisory Council (since 2004). Until 2013 the stock belonged to category 1 (stocks with full analytical assessments and forecasts for catch options). ICES advice was based on the MSY approach, i.e., attaining a fishing mortality rate of no more than F_{MSY} while maintaining the stock above a lower limit biomass (B_{lim}) with at least 95% probability. In this approach, ICES (2015b) used fishing mortality as well as biomass reference points. F_{MSY} was estimated as the fishing mortality, with a given fishing pattern, that gives the long-term maximum yield. The definition of stock targets turned difficult in 2014, due to a regime shift in the Baltic ecosystem (Möllmann et al., 2009) in combination with input data quality concerns (Eero et al., 2015). Because of that, advice on harvest opportunities is recently based on a combined biomass index from two surveys, used as proxy for spawning stock biomass (ICES, 2015b).

Long-term simulations of Eastern Baltic cod development suggest that constant fishing at F_{MSY} probably fulfills at least the ecological objectives (Voss et al., 2014a). However, political decisions on Total Allowable Catches (TACs), which are made on an annual basis, regularly deviated from long-term objectives as specified in MAPs (Carpenter et al., 2016), due to short-term socio-economic considerations (Voss et al., 2016). In phases of low stock size, scientific advice on Eastern Baltic cod repeatedly included a total fishing ban, which was however never implemented. Generally, scientific advice was rarely followed, and TACs were regularly set above the scientific advice (Voss et al., 2016). This confirms that politicians did implicitly take short-term social and economic considerations into account, when deciding on harvest levels. These tactical rather than long-term decisions were, however, taken in a non-transparent way without scientific advice from social sciences or economics.

The aim of this article is to introduce a new way of estimating management advice referred to as an "ecologically-constrained Maximum Economic Yield" (eMEY) strategy, which takes into account ecological criteria as well as short- to medium-term economic costs. We further illustrate what net cost reductions per year are possible applying the eMEY strategy compared with the existing way of setting TACs.

To this end, we advance the concept of Maximum Economic Yield (MEY). The optimal stock under MEY can be smaller or larger than the MSY stock size: While discounting may lead to the famous result of optimal extinction (Clark, 1973), stock-dependent harvesting costs can result in MEY stock sizes above the MSY level (Grafton et al., 2007). This ambiguous effect of the MEY concept onto the biological health of fish stocks motivated the development of eMEY. A second criticism of the MEY principle is linked to its capital-theoretic roots: To quickly realize the long-term benefits of investing in the fish stock, the MEY concept often advocates drastic reductions of harvest and effort levels in the short-run. These drastic short-run policy recommendations were a major problem for implementation in fisheries management, e.g., in Australian fisheries (Dichmont et al., 2010; Kompas et al., 2010). Therefore, we restrict the time period under consideration to 10 years in our eMEY calculations (in contrast to infinity under the traditional MEY approach).

Our new eMEY concept includes social and economic as well as ecological criteria (related to minimum stock sizes) to produce short-term advice that serves as the basis for achieving long-term targets and thus advice for multi-annual management plans. The recent adoption of fishing mortality ranges as a management goal in the Baltic MAP (EU, 2016) offers an opportunity to introduce our new eMEY concept in a real-world fisheries example, without a need for a total regime shift in current advice and management structures.

MATERIALS AND METHODS

Ecological-Economic Model

We used an ecological-economic optimization model for a fishery of an age-structured fish stock with eight age-classes, parameterized for the Eastern Baltic cod trawl fishery. The model calculates the economic optimal fishing effort and related TAC to be set in the next year, using a short- to medium-term perspective, and current stock conditions as input. As ecological side condition, the stock size needed to produce MSY (B_{MSY}) has to be safeguarded. Age-based population numbers, survival rates and body weights are obtained from the standard stock assessments (ICES, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014a). Our model includes a non-linear demand function and stock-dependent harvesting costs. As the cod price is sensitive to harvest levels (Nielsen, 2006) revenue and surplus of ("downstream") users of fish, i.e., the processing industry and fish consumers, are a concave function of harvest (Blenckner et al., 2015). Expected revenues as well as user surplus (a measure of societal benefits from fishing) increase with inter-annual stability of catches. Demand and cost parameters are specifically estimated for this fishery. A full model description, including parameter values and estimation procedures is provided in the Supplementary Material. For a sensitivity analysis, we compute standard deviations of the eMEY catch advice by means of Monte-Carlo simulations. We construct 1,000 random samples for the economic parameters, by using estimates and the covariance matrix of estimates from the OLS regressions.

Evaluating Alternative Advice

Using our ecological-economic model in a hindcast mode, we calculated a hypothetical eMEY advice for the period 1989–2013, i.e., reconstructed economically optimal TACs, while safeguarding ecological criteria. We only used data that had been available in each assessment year: we used the stock structure of the most recent assessment as provided by the ICES Baltic Fisheries Assessment Working Group (WGBFAS) as starting conditions (ICES, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014a) in the optimization, e.g., we used the stock assessment of 1989 to calculate an alternative advice for 1990. We then restarted the eMEY-optimization with the stock assessment in 1990 to give alternative advice for 1991, and so on. To account for the short-term planning horizon of fisheries management as compared to standard long-term economic optimizations, we restricted the optimization period to 10 years. To avoid edge effects, we required the stock size at the end of the optimization period, i.e., after 10 years, to be at or above B_{MSY} (550.000 tons). This ecological-economic advice was than contrasted to original advice given by ICES, actually agreed TAC numbers as well as the unconstraint classical MEY.

The model also offers the opportunity to illustrate and quantify the economic consequences of TAC setting deviating from eMEY. We first quantified these economic costs for the time-series 1989–2013. Afterwards we performed a sensitivity analysis of duration and degree of deviating from eMEY on economic costs. This analysis provides general insights on trade-offs and cost dynamics. Concerning trade-offs, we consider the direct impact on the fishery (fishery profits) on the one hand, and social benefits generated for consumers as well as the processing industry (user surplus) on the other hand. The costs are summed over a period of 10 years, applying a discount rate of 0%. Short-term, tactical considerations, which lead to higher (or lower) exploitation rates than optimal according to our eMEY concept, will have to be counter-balanced in the future. Therefore, we assume the deviations to occur in the first 4 years. Afterwards management switches back to optimal eMEY management, so that minimum ecological constraints (B_{MSY} stock size) are achieved latest after 10 years. The assumption of switching back to optimal management after 4 years is somewhat arbitrary. In the sensitivity analysis we hence quantify the economic effect of non-optimal eMEY fishing over 1–10 year time-spans, as well as different levels of deviation from eMEY advice.

RESULTS

Alternative Advice and Historical Management

Using our ecological-economic optimization model we compared TACs derived according to our eMEY strategy with the catch limits historically advised and subsequently set by the EU fishery management (**Figure 1**; **Table 1**). Until the beginning of the 1990s, TACs following our eMEY concept would have been lower than those advised by ICES based on stock size considerations alone. eMEY-based TAC would have been also lower than politically agreed TAC, thereby having secured a larger spawning stock biomass in future years. However, during low stock sizes (mid 1992–1994 and 2004–2008) eMEY TACs

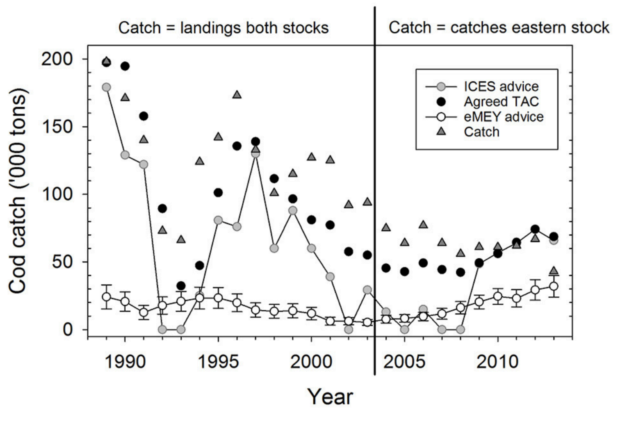

FIGURE 1 | Time-series of ecologically-constrained MEY (eMEY; 10 years time perspective), ICES advice, politically agreed TAC, as well as actual catches for the Eastern Baltic cod fishery. Up to 2003 a common TAC was set for the Eastern and the Western Baltic cod stocks; we westimate the TAC for the eastern stock only, based on the biomass ratio of both stock components. Error bars on eMEY estimates show the results of a sensitivity analysis concerning economic model parameters.

TABLE 1 | Summary of model output, comparing different management regimes considered: eMEY management, ICES scientific advice, politically agreed TACs, and classical MEY.

Year	Next years' harvest				10 years' economic surplus			
	eMEY	ICES	TAC	MEY	eMEY	ICES	TAC	MEY
1989	24.2	179	220	16.6	35.7	29.1	29.1	33.1
1990	20.7	129	210	14.0	33.0	27.1	27.1	30.5
1991	12.7	122	171	9.0	30.7	24.4	24.4	28.7
1992	17.8	0	100	12.4	31.7	24.2	27.3	29.3
1993	20.9	0	40	14.2	33.0	25.0	32.7	30.5
1994	23.4	25	60	16.0	33.7	33.7	32.7	31.3
1995	23.4	80.8	120	16.0	33.1	29.1	27.2	30.7
1996	19.9	76.1	165	13.6	31.6	27.1	23.2	29.3
1997	14.5	130	180	10.7	30.1	18.0	17.7	28.4
1998	13.5	60	140	10.0	29.7	24.4	19.0	28.0
1999	13.9	88	126	10.6	29.8	20.7	19.8	28.3
2000	11.9	60	105	9.2	28.9	22.3	18.4	27.6
2001	6.2	39	105	6.6	25.8	17.3	6.7	26.6
2002	6.3	0	76	6.7	24.2	18.5	8.4	25.1
2003	5.3	29.3	75	6.7	22.2	16.0	7.1	24.2
2004	7.6	13	45.4	6.7	24.0	23.6	16.4	23.7
2005	8.3	0	42.8	7.7	23.6	17.8	17.6	23.6
2006	9.7	14.9	49.2	9.1	24.2	23.9	18.2	24.3
2007	11.7	0	44.3	10.1	26.7	19.8	22.7	26.2
2008	16.2	0	42.3	13.6	27.3	20.3	25.5	26.5
2006	20.5	48.6	49.38	16.5	28.4	26.9	26.8	27.2
2010	24.6	56.8	56.1	19.2	29.7	28.3	28.3	28.2
2011	23.0	64	64.5	17.9	30.8	28.4	28.3	29.1
2012	29.3	74.2	74.2	22.7	32.4	30.4	30.4	30.6
2013	32.0	65.9	68.7	24.8	32.8	31.7	31.5	31.0
Mean					29.3	24.3	22.7	28.1

would have been considerably higher than those based on ICES advice, but always below the TACs eventually decided. Actual catches have been found to be either well below the agreed TACs (in the beginning and end of the time-series) or overshoot the allowed TAC (most years in 1993–2010; **Figure 1**). In contrast to historical ICES advice, eMEY-based harvest recommendations would have always been positive, i.e., never suggesting a total fishing ban. During phases of low stock size, when a rebuilding of the stock biomass was urgently needed, eMEY-based TACs would have been closer to the realized political TAC decisions compared to the historical ICES advice.

Furthermore, annual fluctuations in eMEY based TACs are much smaller than in the other two management options, and therefore best meet the objective of inter-annual stability of catches, which is often put forward by fishermen and managers (Rindorf et al., 2016). However, even under the relatively stable eMEY management, maximum year-to-year changes in TACs range from a reduction of −11.171 tons (−12%; year 1982/1983), to an increase of +6.283 tons (+26%; year 2011/2012).

The eMEY-based advice for next years harvest levels is, however, higher as compared to the classical MEY approach (**Table 1**). The classical MEY strategy operates with an infinite time horizon, while our new eMEY explicitly takes a more short-to medium-term perspective. The restriction of the optimization period to 10 years results in higher initial catches, and a slower stock rebuilding as under MEY management.

Typically, MEY management builds up the stock fastest, while stock recovery under TAC management is slowest. Our eMEY solution forms a compromise between the ecological and economic objectives. In years with the special case of zero catch advice (e.g., 1992), the resulting fast stock recovery is economically non-optimal (Figure S1; see Supplementary Material).

In a next step, we quantified the economic costs of deviating from the optimal, integrative eMEY advice for the historic time-series. These costs could have been saved in the past, if the eMEY strategy had been applied. In extreme cases, the costs sum to >1,200 million € over a 10 year period when the historical advice would have been used, and almost 2,000 million € when the realized TAC decisions would have been applied (**Figure 2**). Annual fluctuations are large until 2008, however, since 2009 advice and TAC decision are in close agreement, but still slightly above eMEY advice. This leads to costs for fishery and society. The share of total costs carried by the fishery is variable for both management regimes. However, the fishery always had to accept only a smaller share of the total costs.

Societal Costs of Tactical Management Options

Due to tactical consideration, politicians often choose to set a TAC, which is not in line with scientific recommendations. Our approach offers the opportunity to project the societal costs of deviating from the ecological-economic optimum, i.e., the effect of setting a higher or lower TAC than scientifically advised according to our eMEY concept. The costs depend on the degree of deviation as well as the duration of the deviation (**Figure 3**). As an example, we show the results for the year 1994.

After a period of strong decline in stock biomass and associated fishing options, the Eastern Baltic cod stock was assessed to have considerably increased in 1994, partly due to improved environmental conditions. Management decisions at this perceived turning point are particularly interesting, as the objective of further stock recovery had to be traded against increased harvesting prospects. The eMEY advice for 1994 amounts to 30.500 tons (harvest multiplier = 1.0 on x-axis of **Figure 3A**). ICES advice during that year was a factor of 0.82 lower, emphasizing the ecological objective of fast stock rebuilding. The politically agreed TAC ended up a factor of 1.98 higher, setting priorities on the short-term harvest quantities. Total economic costs of scientific advice would have been only 5 million €, while the TAC decision caused costs of ca. 400 million € over 10 years. In the case of scientifically advised under-fishing (caused by the sole objective of fast stock recovery; harvest multiplier: 0.82), economic losses mainly occurred in the user surplus, i.e., in the processing industry and on the consumer side (−10.8 million €; **Figure 3A**). Fishery profits would actually increase by this decision by +4.6 million €. The politically agreed TAC (overfishing by a factor of 1.98) caused total economic losses of 76.4 million €, which are mainly paid for by the fishing industry (−62.2 million €) and only to a lesser part by consumers and the processing industry (−14.2 million €).

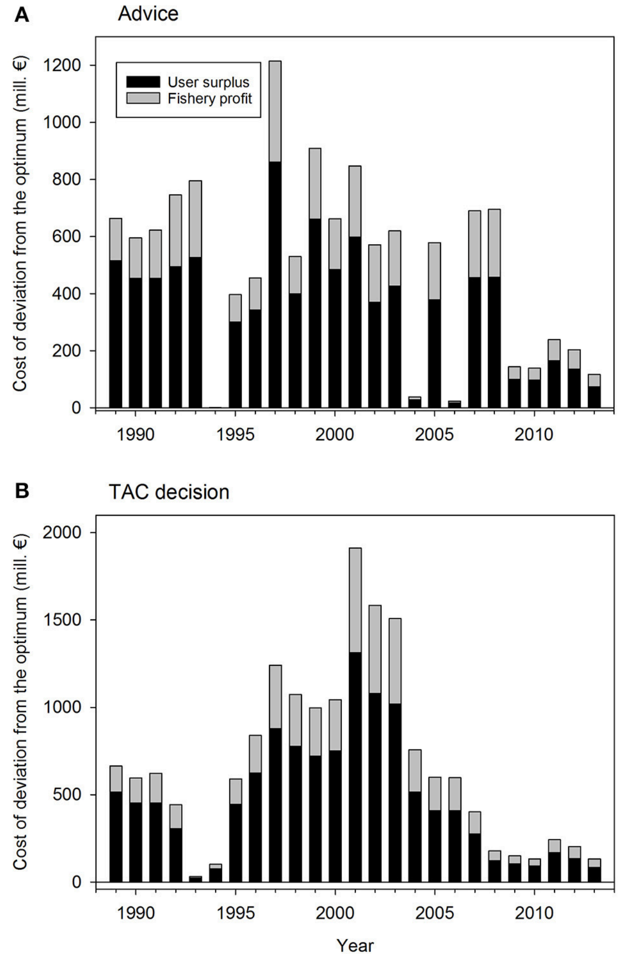

FIGURE 2 | Economic costs of deviating from advice: time-series 1989–2013. Costs arising when following standard scientific advice **(A)** or when following political TAC decisions **(B)**.

In more general terms, the costs of deviations from the eMEY optimum increase non-linearly with both over- and under-fishing the resource (**Figure 3A**). However, as illustrated in the 1994 example, consequences for processors and consumers (user surplus) as compared to profits for the fishery differ. In the case of overfishing the larger fraction of the costs is paid by the fishery, and to a lesser extent by the processing industry and the consumers. The fraction of costs occurring in fishing profits decreases with increasing over-fishing, but even at a TAC being set by a factor of 1.5 higher than optimal, still 100% of all costs occur to the fishery. Since TACs have been regularly set above the optimum, most of the time the economic burden of overfishing is carried by fishermen. Underfishing, on the other hand, is particularly costly for processors and consumers, as reduced catch quantities lead to higher prices for the resource. Moderate under-fishing (harvest multiplier >0.5) only causes costs for consumers and the processing industry, not for the fishery.

The impact of a variable duration of the deviation from eMEY advice (between 1 and 9 years) is investigated closer in **Figures 3B,C**. We calculated the effects for harvest multipliers corresponding to TAC options as recommended by ICES (slight over-fishing by a factor of 1.07) and compared those to historically agreed TAC levels (severe over-fishing by a factor of 2.02). As observed for degree of deviation, costs increase in a non-linear way with continued duration of deviating from the optimum. The economic costs of slight over-fishing (**Figure 3B**) are comparatively low. In 1994 the special situation occurred that the scientifically recommended fishing level would have resulted in benefits for the fishery up to a duration of 3 years (negative costs in **Figure 3B**), but are surpassed by costs to the processing industry and consumers. Effects of severe over-fishing are much more costly (**Figure 3C**): seven years of continued strong over-fishing would result in costs of >200 million €. The larger share of costs would be allotted to the user surplus.

DISCUSSION

Scientific advice on harvest opportunities is currently given on basis of long-term ecological objectives, i.e., the MSY objective. Decision makers are, however, confronted in their daily lives with short-term socio-economic pressures, which they have to account for in their decisions (Voss et al., 2016). This often leads to a mismatch between scientific advice and subsequent politically agreed catch quantities (Daw and Gray, 2005; Carpenter et al., 2016). How exactly socio-economic objectives have been weighted against ecological objectives during the decision process stays, however, in-transparent, and is not based on scientific advice.

Here, we developed a new way of estimating management advice, which takes ecological as well as economic, short- to medium-term objectives explicitly into account. Using an ecological-economic optimization model of a fishery on an age-structured population we provide additional fishing options, and illustrate and quantify the effect of deviating from the optimum (i.e., setting higher or lower TACs than economically optimal). This kind of information could be used for constructing integrated advice, which is one step forward toward EBFM.

There is a clear need to change the existing management toward an eMEY strategy in order to reach the overall objective of EBFM, which is to sustain healthy marine ecosystems and the fisheries they support, including social and economic benefits (Pikitch et al., 2004). Ecosystem-based Fisheries Management "recognizes the physical, biological, economic, and social interactions among the affected components of the ecosystem and attempts to manage fisheries to achieve a stipulated spectrum of societal goals, some of which may be in conflict" (Marasco et al., 2007). The challenge for researchers in the field of resource management is to provide decision makers with trade-offs among alternative management goals in a way that highlights the outcomes of alternative management policies in a transparent, yet scientifically rigorous manner (Dichmont et al., 2013). These aspects need to be included already in the advice-giving process in order to provide a sound and transparent basis for political management decisions. Otherwise, decision-makers

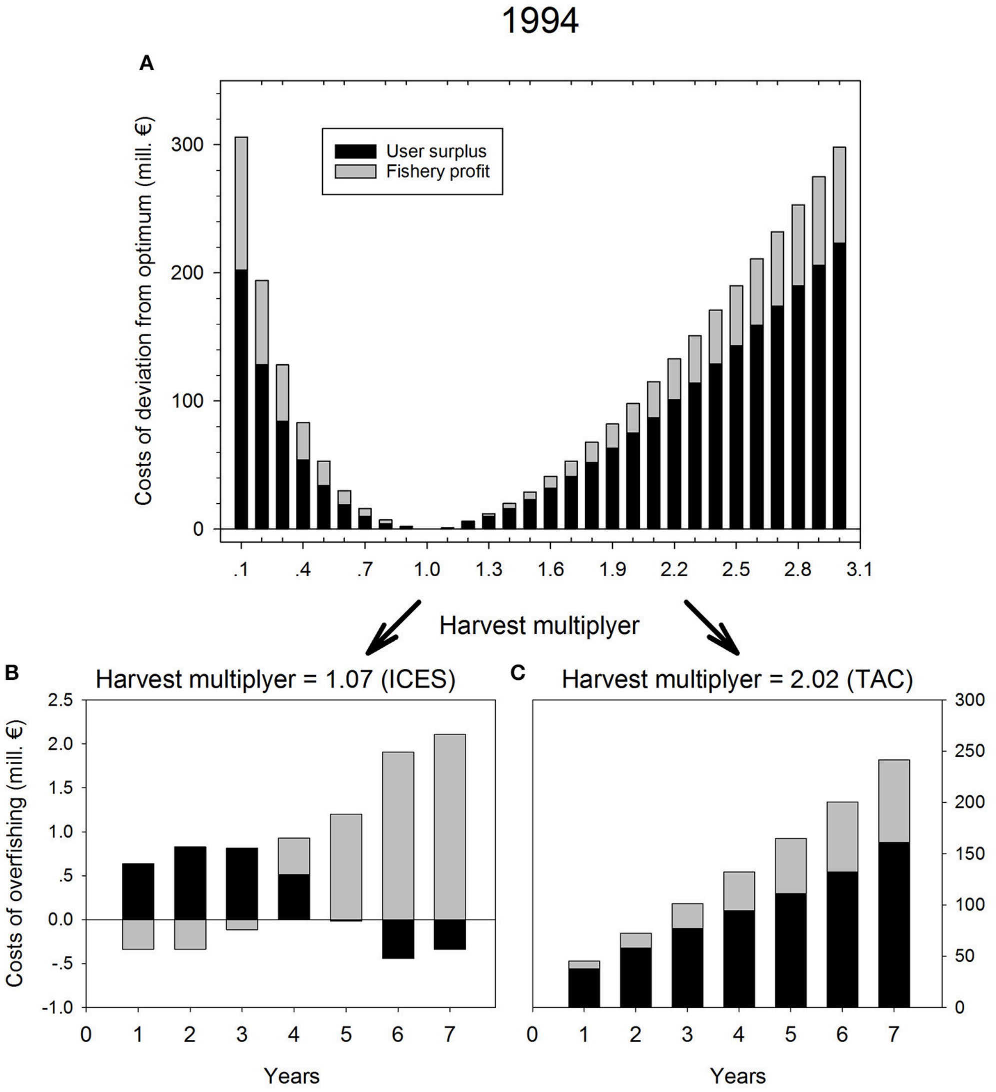

FIGURE 3 | Economic costs of over- or under-fishing for the year 1994. Costs for the fishery in terms of foregone fishery profits as well as for the consumers and fish processing industry (user surplus). Costs depend on the degree of deviation from ecological-economic optimal harvest (**A**; harvest multiplier of 1.0 = optimal) as well as on duration of sub-optimal management **(B,C)**. Costs are summed over a simulated 10 years period.

will continue to subjectively consider social and economic factors in addition to biological and ecological components, with the consequence of setting TACs on levels that often considerably exceed the scientific advice (Rosenberg, 2003). Our new eMEY strategy supports the goals of EBFM by providing ecological-economic integrated advice, and by making the costs of alternative management options transparent.

The political will to proceed to EBFM (including socio-economic considerations) is formulated in the latest reform of the European Common Fisheries Policy (CFP). It not only emphasizes its commitment to pursuing MSY but also that the CFP shall implement an ecosystem-based approach to fisheries management (EU, 2013). A long-term stable, secure, and healthy food supply is to be ensured by establishment of multiannual plans (MAPs) for fishery management governed by EBFM (EU, 2013; Hoffmann and Quaas, 2016). For the Baltic Sea, the European Commission has proposed creating a MAP, primarily focusing on cod, herring, and sprat (COM, 2014). The plan aspires to establish a multispecies fisheries plan taking into account the dynamics between the above-mentioned target fish species, and it is intended to include economic and social aspects besides the customary bio-ecological aspects. The plan is recently agreed (EU, 2016), but discussions continue and policymakers are actively seeking scientific advice in support of policy development. In parallel, ICES is discussing ways to progress the delivery of more integrated advice, e.g., amalgamated across scientific disciplines, sectors and resource and environmental issues (ICES, 2014b). These factors provide an opportunity to transfer new interdisciplinary knowledge to support developing judicious CFP-related management applications.

The transition from the current management system, which is mainly based on biological considerations, toward a more integrated ecological-economic assessment and advice system seems difficult. However, the request for enhanced stability of fishing opportunities and reduced uncertainty (Rindorf et al., 2016) is encompassed in the draft MAP proposal for the key commercial Baltic Sea fisheries (EU, 2016). The MAP incorporates the best scientific knowledge available, and it leaves space for trade-off analysis, as the MSY fishing mortalities (F_{MSY})—forming the basis for setting annual TACs—are provided as a range of values for each of the stocks, instead of a non-negotiable F_{MSY} point estimate. Within this range, the system is already now open to include economic considerations, like the eMEY strategy.

We propose a stepwise transition, which offers progress, but still continuity. In the frame of the ICES Workshop on DEveloping Integrated AdviCE for Baltic Sea ecosystem-based fisheries management (WKDEICE) a theoretical framework was established (ICES, 2016). Bio-economic modeling (**Figure 4**; blue boxes), which is informed via an environmentally sensitive stock-recruitment function, adds another dimension to integrated advice. The explicit consideration of fisheries being an economic activity, which is securing the livelihood of people, offers additional F-options. Such options are derived in a transparent way and offer the basis for discussions on potential trade-offs (Quaas et al., 2017). A formal way of weighting is possible, but not necessarily needed. In any case, incorporation of economics might reduce the gap between current scientific advice and politically agreed TACs, and thereby contribute to an improved societal acceptance of scientific advice.

It is crucial for acceptance of our new strategy (by scientists as well as stakeholders), that the underlying model assumptions, limitations, and uncertainties are communicated. Our results are strongly driven by the estimates of cost and price parameters: We use empirical data, which are specific for the eastern Baltic cod fishery (see Supplementary Material). We allow for a time-trend in the cost parameter, and include the interplay with important potential substitutes, i.e., Northeast Artic cod catches when specifying the demand function. Nonetheless, we provided a thorough sensitivity analysis of the economic parameters to assess how robust our results are. Despite considerable uncertainties (see **Figure 1**), the main findings remain valid. We restricted the time-horizon of the eMEY calculation to 10 years. Such a restriction to a short- to medium-term planning horizon may in fact be seen as another way of expressing higher interest rates, and we therefore decided to apply an interest rate of 0% to avoid confounding effects. Using an interest rate of >0% would further increase the catch quantities in the first years. Additionally, there are other external and internal factors, which might affect costs, prices, and demand, e.g., size and quality of the fish, which are not included in the model, and will add further uncertainty to the results.

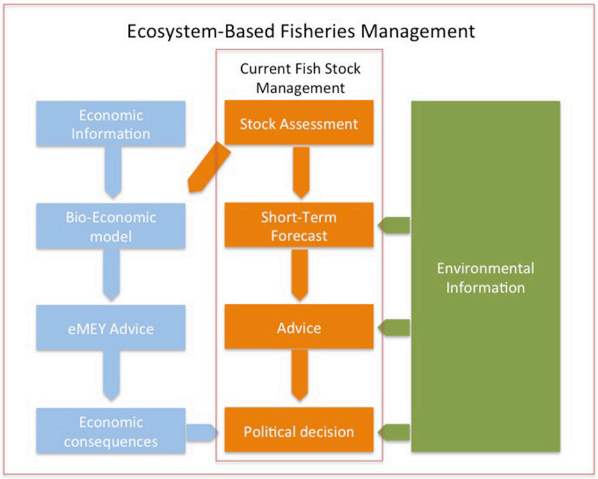

FIGURE 4 | Incorporation of ecological-economic modeling and environmental information in the standard advice process to proceed to a more integrated advice, and ecosystem-based fisheries management.

As the Baltic ecosystem and its associated fishery, including its socio-economic aspects, are frequently changing due to the influence of various human and naturally induced drivers (Möllmann et al., 2009; Reckermann et al., 2012), it is prudent to regularly review, revise, and adapt all assumptions involved in the advice giving process. This is not least because MSY as well as eMEY value estimates are dependent on the changing status of the ecosystem (ICES, 2014c, 2015a). Such periodic quality control must depend on evidence-based scientific advice, but should be shaped by full openness and transparency involving dialogue and feedback on preferred options from stakeholders, i.e., advancing to a full “transdisciplinarity” approach (Schwach et al., 2007).

Finally, in a multi-user or multi-species context different management strategies will result in winners and losers (Voss et al., 2014a,b). This calls for a debate on who should actually be considered and represented in stakeholder consultations. Society as a whole, with an interest in fish consumption, might currently be under-represented, as formal consumer associations are often missing.

AUTHOR CONTRIBUTIONS

RV, MT, and CM chaired the original workshop this paper is based on. RV, JS, MT, and CM designed the work. MQ and MS prepared the economic input data and run the bio-economic analysis. JS and MQ prepared the ecological input data. RV wrote the paper. All authors contributed in interpreting the results and contributed to critically review the text.

FUNDING

RV and JS were funded by the Cluster of Excellence 80 “The Future Ocean.” The “Future Ocean” is funded within the framework of the Excellence Initiative by the Deutsche Forschungsgemeinschaft (DFG) on behalf of the German federal and state governments.

MT was funded by the BalticEye and DEMO Stockholm University projects. Baltic Eye is partnership between Stockholm

University and foundation BalticSea2020 and DEMO—"DEMOnstration exercise for Integrated Ecosystem Assessment and Advice of Baltic Sea cod" was funded by Granholm Stiftelse.

ACKNOWLEDGMENTS

The authors wish to thank all members participating in the ICES Workshop on DEveloping Integrated AdviCE for Baltic Sea ecosystem-based fisheries management (WKDEICE) for valuable support and discussions.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://journal.frontiersin.org/article/10.3389/fmars.2017.00209/full#supplementary-material

REFERENCES

Blenckner, T., Llope, M., Möllmann, C., Voss, R., Quaas, M. F., Casini, M., et al. (2015). Climate and fishing steer ecosystem regeneration to uncertain economic futures. *Proc. R. Soc. B* 282, 2014–2809. doi: 10.1098/rspb.2014.2809

Carpenter, G., Kleinjans, R., Villasante, S., O'Leary, B. C. (2016). Landing the blame: the influence of EU Member States on quota setting. *Mar. Policy* 64, 9–15. doi: 10.1016/j.marpol.2015.11.001

Clark, C. W. (1973). The economics of overexploitation. *Science* 181, 630–643. doi: 10.1126/science.181.4100.630

COM (2014). *Proposal for a Regulation of the European Parliament and of the Council Establishing a Multiannual Plan for the Stocks of Cod, Herring and Sprat in the Baltic Sea and the Fisheries Exploiting those Stocks, Amending Council Regulation (EC) No 2187/2005 and Repealing Council Regulation (EC) No 1098/2007*. European Commission COM. Available online at: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014PC0614&from=EN

Daw, T., and Gray, T. (2005). Fisheries science and sustainability in international policy: a study of failure in the European Union's Common Fisheries Policy. *Mar. Policy* 29, 189–197. doi: 10.1016/j.marpol.2004.03.003

Dichmont, C. D., Ellis, N., Bustamante, R. H., Deng, R., Tickell, S., Pascual, R., et al. (2013). Evaluating marine spatial closures with conflicting fisheries and conservation objectives. *J. Appl. Ecol.* 50, 1060–1070. doi: 10.1111/1365-2664.12110

Dichmont, C. M., Pascoe, S., Kompas, T., Punt, A. E., and Deng, R. (2010). On implementing maximum economic yield in commercial fisheries. *Proc. Natl. Acad. Sci. U.S.A.* 107, 16–21. doi: 10.1073/pnas.0912091107

Eero, M., Hjelm, J., Behrens, J., Buchmann, K., Cardinale, M., Casini, M., et al. (2015). Eastern Baltic cod in distress: biological changes and challenges for stock assessment. *ICES J. Mar. Sci.* 72, 2180–2186. doi: 10.1093/icesjms/fsv109

EU (2013). *Regulation 1380/2013 of the European Parliament and of the Council of 11 December 2013 on the Common Fisheries Policy, Amending Council Regulations (EC) No 1954/2003 and (EC) No 1224/2009 and Repealing Council Regulations (EC) No 2371/2002 and (EC) No 639/2004 and Council Decision 2004/585/EC.*

EU (2015). *Regulation 2015/812 of the European Parliament and of the Council of 20 May 2015 Amending Council Regulations (EC) No 850/98, (EC) No 2187/2005, (EC) No 1967/2006, (EC) No 1098/2007, (EC) No 254/2002, (EC) No 2347/2002 and (EC) No 1224/2009, and Regulations (EU) No 1379/2013 and (EU) No 1380/2013 of the European Parliament and of the Council, as Regards the Landing Obligation, and Repealing Council Regulation (EC) No 1434/98.*

EU (2016). *Regulation 2016/1139 of the European Parliament and of the Council Establishing a Multiannual Plan for the Stocks of Cod, Herring and Sprat in the Baltic Sea and the Fisheries Exploiting Those Stocks, Amending Council Regulation (EC) No. 2187/2005 and Repealing Council Regulation (EC) No. 1098/2007*.

Grafton, R. Q., Kompas, T., Hilborn, R. W. (2007). Economics of overexploitation revisited. *Science* 318:1601. doi: 10.1126/science.1146017

Hoffmann, J., Quaas, M. F. (2016). Common pool politics and inefficient fishery management. *Environ. Resour. Econ.* 63, 79–93. doi: 10.1007/s10640-014-9842-4

ICES (1989). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (1990). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (1991). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (1992). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (1993). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (1994). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (1995). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (1996). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (1997). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (1998). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (1999). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (2000). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (2001). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (2002). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (2003). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (2004). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (2005). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (2006). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (2007). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (2008). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (2009). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (2010). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (2011). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (2012). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (2013). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (2014a). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (2014b). *ICES Strategic Plan 2014–2018.*

ICES (2014c). *The Maximum Sustainable Yield Concept. ICES Advice 2014, Book 1, Section 1.2.1.3.* Available online at: http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2014/2014/1.2_Advice_basis_2014.pdf

ICES (2015a). *Report of the Baltic Fisheries Assessment Working Group (WGBFAS).* Technical Report, International Council for the Exploration of the Sea.

ICES (2015b). *ICES Advice Basis, ICES Advice 2015, Book 1.* Available online at: http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2015/2015/General_context_of_ICES_advice_2015.pdf

ICES (2016). *Report of the Workshop on DEveloping Integrated AdviCE for Baltic Sea Ecosystem-Based Fisheries Management (WKDEICE).* ICES CM 2016/SSGIEA:13, Helsinki.

Kompas, T., Dichmont, C. M., Punt, A. E., Deng, A., Nhu Che, T., Bishop, J., et al. (2010). Maximizing profits and conserving stocks in the Australian Northern Prawn Fishery. *Agric. Resour. Econ.* 54, 281–299. doi: 10.1111/j.1467-8489.2010.00493.x

Larkin, P. A. (1977). An epitaph for the concept of maximum sustained yield. *Trans. Am. Fish. Soc.* 106, 1–11. doi: 10.1577/1548-8659(1977)106<1:AEFTCO>2.0.CO;2

Marasco, R. J., Goodman, D., Grimes, C. B., Lawson, P. W., Punt, A. E., and Quinn, T. J. II. (2007). Evaluating marine spatial closures with conflicting fisheries and conservation objectives. *Can. J. Fish. Aquat. Sci.* 64, 928–939. doi: 10.1139/f07-062

Möllmann, C., Diekmann, R., Müller-Karulis, B., Kornilovs, G., Plikshs, M., Axe, P. (2009). Reorganization of a large marine ecosystem due to atmospheric and anthropogenic pressure: a discontinuous regime shift in the Central Baltic Sea. *Global Change Biol.* 15, 1377–1393. doi: 10.1111/j.1365-2486.2008.01814.x

Nielsen, M. (2006). Trade liberalisation, resource sustainability and welfare: the case of East Baltic cod. *Ecol. Econ.* 58, 650–664. doi: 10.1016/j.ecolecon.2005.08.013

NOAA (2015). *NOAA RESTORE Act Science Program – Science Plan.* Available online at: www.restoreactscienceprogram.noaa.gov

Pikitch, E. K., Santora, C., Babcock, E. A., Bakun, A., Bonfil, R., Conover, D. O., Dayton, P., et al. (2004). Ecosystem-based fishery management. *Science* 305, 346–347. doi: 10.1126/science.1098222

Quaas, M. F., Stoeven, M., Klauer, B., Schiller, J., Petersen, T. (2017). Windows of opportunity for sustainable fisheries management: the case of Eastern Baltic cod. *Environ. Resour. Econ.* doi: 10.1007/s10640-017-0122-y. [Epub ahead of print].

Reckermann, M., Brander, K., MacKenzie, B., Omstedt, A. (2012). *Climate Impacts on the Baltic Sea: From Science to Policy*. Berlin: GKSS School on Environmental Research; Springer.

Rindorf, A. Dichmont, C. M., Thorson, J., Charles, A., Worsøe Clausen, L., Degnbol, P., Garcia, D., et al. (2016). Quo Vadimus: Including ecological, economic, social and institutional considerations when setting targets and limits for multi species fisheries. *ICES J. Mar. Sci.* 74, 453–463. doi: 10.1093/icesjms/fsw226

Rosenberg, A. A. (2003). Managing to the margins: the overexploitation of fisheries. *Front. Ecol. Environ.* 1, 102–106. doi: 10.1890/1540-9295(2003)001[0102:MTTMTO]2.0.CO;2

Schwach, V., Bailly, D., Christensen, A.-S., Delaney, A. E., Degnbol, P., van Densen, W. L. T., et al. (2007). Policy and knowledge in fisheries management: a policy brief. *ICES J. Mar. Sci.* 64, 798–803. doi: 10.1093/icesjms/fsm020

United Nations (1982). *Convention on the Law of the Sea (Montego Bay, 10 December 1982, in force 16 November 1994) 1833 UNTS 396.* Article 61 and 119.

United Nations (2002). *Report of the World Summit on Sustainable Development, A/CONF.199/20.*

United Nations (2015). *Transforming Our World: The 2030 Agenda for Sustainable Development, A/RES/70/1.*

Voss, R., Hoffmann, J., Llope, M., Schmidt, J. O., Möllmann, C., Quaas, M. F. (2016). *Political* overfishing: social-economic drivers in TAC setting decision. Kiel University Working Paper. Available online at: https://www.eree.uni-kiel.de/de/Political%20overfishing%2011%20Sep_Julia.pdf

Voss, R., Quaas, M. F., Schmidt, J. O., Hoffmann, J. (2014a). Regional trade-offs from multispecies maximum sustainable yield (MMSY) management options. *Mar. Ecol. Prog. Ser.* 498, 1–12. doi: 10.3354/meps10639

Voss, R., Quaas, M. F., Schmidt, J. O., Tahvonen, O., Lindegren, M., Möllmann, C. (2014b). Assessing social-ecological trade-offs to advance ecosystem-based fisheries management. *PLoS ONE* 9:e107811. doi: 10.1371/journal.pone.0107811

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.