AN UPDATED SUMMARY OF MODEL ADEQUACY FOR DESIGNATING KEY LOW TROPHIC LEVEL SPECIES

Consultancy Report

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INTRODUCTION

Low trophic level (LTL) species are small pelagic fish and invertebrates that exhibit schooling behavior. In the last two decades, research on these species and their supportive role to marine ecosystems has explored some of the issues with managing these stocks in a way that accounts for potential ecosystem impacts of fisheries for LTL species. Ecosystem models can be used to assess the potential ecosystem impacts of fishing LTL species. Essington & Plagányi (2013, 2014) proposed a framework for evaluating the utility of ecosystem models for classifying LTL species as "key" (Filter 1 of the MSC standard for LTL stocks).

This report summarizes models built or updated since Essington & Plagányi (2013, 2014). In cases where new models have been constructed for ecosystems that were previously evaluated, the new scores are compared with the original ones. The aims of this work were to:

1. Evaluate more recent models for each of the ecosystems below to determine information available for assessing key LTL status (Filter 1)
2. Evaluate new models for ecosystems not previously assessed to determine information available for assessing key LTL status (Filter 1)
3. Evaluate all models to assess benchmarks under Filter 2 (i.e. which stocks will need to adopt default levels, which have information that could lead to lower biomass limit/target)
4. Evaluate whether any species are flagged as key LTL when there is plausible evidence to the contrary
5. If needed, suggest modifications to the certification requirements and/or guidance to allow truly low-risk fisheries to meet the Filter 1 requirements, while ensuring that high-risk fisheries are correctly classified at Filter 1.

METHODS

Ecosystem models containing LTL species were evaluated for their potential to provide information for assessing Filter 1 and Filter 2. The list of models included 8 total models (Table 1), representing six unique ecosystems. In cases where models were dynamic, the connectance scores were based on either the most recent year of data (when the publication compared two ecosystem states) or the start year (when the publication was looking at projections from an initial state).

Table 1. Summary of new models and those previously evaluated in Essington and Plagányi (2013).

	Initial assessment (2013)		**Most recent assessment(s) (2019)**	
Stock(s)	**Model ecosystem**	**Reference**	**Updated model ecosystem**	**Reference**
California Current Sardine *Sardinops sagax*	Northern California Current 1960-2004	Field *et al.* (2006)	Northern California Current 2000-2014	Koehn et al. 2016
			Northern California Current 2013+	Kaplan et al. 2017; Marshall et al. 2017
			Northern California Current	Punt et al. 2016
Barents Sea Capelin *Mallotus villosis*	Barents Sea 1973-1999	Blanchard *et al.* (2002)	Barents Sea and Norwegian Sea 1950-2001	Skaret & Pitcher 2016
Chesapeake Bay Menhaden *Brevoortia tyrannus*	Chesapeake Bay 1950-2002	Christensen *et al.* (2009)	Chesapeake Bay 1982-2013	Buchheister et al. 2017
Great Lakes alewife *Alosa pseudoharengus* and rainbow smelt *Osmerus mordax*	not previously evaluated		Lake Michigan 1962-2008	Tsehaye et al. 2014
Australian redbait *Emmelichthys nitidus*	not previously evaluated		Southern Australia 1994-2003	Goldsworthy et al.; published in Gales et al. 2003
Brazilian long-finned squid *Loligo plei (Doryteuthis plei)*	not previously evaluated		South Brazil bight 2001-2003	Gasalla et al. 2010

Aggregation

In cases where there were multiple age or size classes for a single species, they were aggregated. The biomass ratio for the species was calculated from the sum of the biomass of the individual age or size classes. The diet proportions for the aggregate species were calculated as the weighted mean of the diet proportions of all the age or size classes of that species, weighted by the proportional consumption by each of those classes:

$$p_{i,j} = \sum_{x=1}^{n} p_x w_x$$

Where $p_{i,j}$ is the proportion of prey *j* in the diet of predator species *i* , *n* is the number of predator age or size classes in question, p_x is the diet proportion of prey *j* for age or size class *x* and w_x is the weight of age class *x* based on its consumption relative to the other age classes (consumption of age class x relative to the other age classes in the species). For predators of LTL species, the total contribution of the LTL species to a given predator was calculated as the sum of the diet proportions of that predator for all age/size classes of the LTL species.

Connectance

The SURF index (SUpportive Role to Fishery ecosystems) weights food web connectance by the importance of trophic connections and is thus a more stable index of food web connectance. The SURF index is stable at various degrees of aggregation at the predator level but is less stable in cases where LTL species are aggregated.

NEW APPROACHES TO FILTER 1: HOW DO WE IDENTIFY KEY LTL SPECIES?

Of the five models evaluated here that has the data and models available to calculate connectance, Barents Sea capelin and South Brazil longfin squid were the only stocks that were not disqualified as “non-key LTL” based on the MSC standard (Table 3; Figure 1-5). Currently a connectance value of <4% indicates non-key LTL, and a species has to have a connectance >8% in order to be considered key. Among the four LTL species with adequate models and data, none of the LTL species considered had connectance values above this threshold. The only LTL species close to the threshold for key-ness based on connectance were krill in the Barents Sea ecosystem (connectance = 0.08), although they are not the focal LTL species in that analysis. Krill in the Barents Sea also qualify as key based on the SURF index (SURF = 0.0067).

Although the SURF index is robust to the number of connections in the ecosystem, it is sensitive to the aggregation at the level of the LTL species, as noted by Essington and Plaganyi (2013). This is the case for California sardine, which has a SURF index of 0.00012 by itself but has a higher SURF score when aggregated with other forage species (specifically anchovy; Koehn *et al.*, 2016). Sardine and anchovy may be functionally equivalent for some predator species, and together have a SURF index of 0.0012, which is above the threshold (Koehn *et al.*, 2016). Koehn et al. (2016) also compared other aggregate groups and found that no pairings of forage species in the California Current ecosystem had a SURF index greater than 0.005. This might be due to the fact that the models used to set the thresholds for the SURF index are less complex than the Ecopath model (see Essington and Plagányi, 2014; and discussion in Koehn *et al.*, 2016). It’s also possible that more keyness would be detectable if it were quantified on a small spatial scale, where some forage species are spatially restricted and/or predators are limited to foraging in smaller areas.

Aggregation of age classes into species may have similar effects on measures of keyness. Here, age and size classes were aggregated into species in order to ensure that ecosystem models were comparable to one another (as in Essington and Plagányi, 2013; Table 2), but SURF indices are also compared between a case where LTL species are divided into age classes and when they are not (Table 2; Figure 6). In this comparison, predators are still aggregated but menhaden are kept in the size-based categories they were originally modeled as in Buchheister et al. (2017), instead of being aggregated to the species level as in Essington & Plagányi (2013). The aggregate SURF index is higher than the index of each size class, illustrating a similar issue to Koehn et al. (2016) in detecting key species. This suggests that key species may escape identification if they are not aggregated in ecologically relevant groups.

There are also limitations to the approach for freshwater ecosystems, because of the ecological differences between freshwater and marine systems. Here, Great Lakes alewife and rainbow smelt were included in the list of potential LTL species, but connectance could not be calculated by diet proportion as diet in the model is determined by size and habitat overlap between predator and prey instead of species-specific trophic interactions. However, even in a case where an Ecopath model is available for an aquatic ecosystem, the interpretation of a food web metric like connectance would be different for a number of reasons. Freshwater food webs have fewer species, which might mean that connectance indices would be higher than one would expect in marine systems (requiring different cutoffs for “keyness”). Additionally, food chain length and predator diversity are linked to area in freshwater systems (Post *et al.*, 2000), which could have different effects on a measure of connectance used for other ecosystems: in a smaller area, having a simpler food web could lead to a very high SURF index. It could also lead to lower scores if predator diversity is not high but the ecosystem as a whole has a lot of trophic interactions. While larger lakes might be somewhat similar in trophic structure to marine ecosystems, food web structure may also be different because of different nutrient pathways or human disturbance.

Food webs in lakes are also susceptible to flows into the ecosystem like allochthonous nutrients and changes in the flow of nutrients and/or organisms between different habitats in the same lake (see Ives *et al.*, 2019 for a review of these processes in the Laurentian Great Lakes). The resilience of lakes to perturbations (e.g., through fishing an LTL species) is variable and thus would require additional investigation to determine what appropriate thresholds for “keyness” would be (McMeans *et al.*, 2016).

Table 2. Connectance when menhaden are grouped by size and when they are aggregated to the species level.

Functional group	SURF	Connectance	Biomass proportion
Atlantic menhaden (small)	0.00003	0.02922	0.00257
Atlantic menhaden (medium)	0.00006	0.02795	0.01420
Atlantic menhaden (large)	0.00004	0.02541	0.00832
Atlantic menhaden (aggregated)	**0.00035**	**0.03066**	**0.02509**

ASSESSING FILTER 2: POTENTIAL FOR IDENTIFYING REFERENCE POINTS

Essington and Plagányi (2013) found few stocks in the MSC program for which ecosystem models had been built in order to test the impacts of fishing on the ecosystem. Of the eight models evaluated here, five were fitted to time series data, and one was fitted to environmental time series data (the MICE model for the California Current) (Punt *et al.*, 2016). Two of the eight models had environmental variables as drivers for the ecosystem model, and half of the models accounted for uncertainty in parameter values, observation error, or estimates of fishery impacts. In some cases (e.g., for Atlantis models) it is not feasible to carry out multiple simulations given the structure and run time of the model. In cases where a large, complex model with long run-times is the only ecosystem model available, it may be necessary to have a structurally simpler model available for the same ecosystem to make any conclusions about parameter uncertainty.

Table 3. Summary of data and model availability for LTL stocks included in this report. This table contains the same information as Table 5 in Essington and Plagányi (2013).

	Adequate Data / Model					
Stock(s)	**Filter 1** (identifying key LTL species)	**Filter 2** (setting biomass reference points)	**Connectance** (Proportional connectance)	**Connectance (**weighted SURF index)	**Consumer biomass proportion**	**Age/size aggregated for calculations?**
California Current Sardine *Sardinops sagax* – Ecopath model	Yes	Not sure	0.0254	0.00012	0.025059	--
Atlantis model	Yes	Not sure				
MICE model	No	Yes[1]				

1 Since this MICE model is constructed with two primary predators of interest, the EBFM reference points that could come from this model would be best suited to managing those species.

Barents Sea Capelin *Mallotus villosis*	Yes	Yes	0.0554[2]	0.00039	0.001679	✓
Chesapeake Bay Menhaden *Brevoortia tyrannus*	Yes	Yes	0.030656	0.00035	0.02508	✓
Great Lakes alewife *Alosa pseudoharengus* and rainbow smelt *Osmerus mordax*	No (SCAA model)	No				
Australian redbait *Emmelichthys nitidus*	Yes	Yes	0.00018[3]		0.01288	--
Brazilian long-finned squid *Loligo plei (Doryteuthis plei)*	Yes	No	0.12781	0.003277	0.04137	--

CONCLUSIONS AND RECOMMENDATIONS

The characteristics currently used by MSC to assess key LTL status are robust when certain types of ecosystem models have been constructed for the stock of interest. Some of the considerations, like food web connectance, were designed with large ecosystem models like Atlantis and Ecosim in mind. These large ecosystem models were also used to determine what the thresholds should be for considering a species “key”. The approach still works effectively when those models are available. Other types of ecosystem models with simpler structures may need different thresholds for determining the ecosystem effects of fishing that LTL species.

In the models tested here, it appears that many LTL species do not qualify as “key” by MSC standards, and this may be due to issues with aggregation of trophic guilds. In many cases, species not classified as “key” under the current framework would potentially be key if grouped with other LTL species (e.g., sardine and anchovy in the California Current). Based on the models in this report, the current framework is robust to false specification of LTL status but could fail to identify important species that are parts of key guilds. In cases where multiple LTL species in the same ecosystem are being evaluated for certification, it is important to consider whether together they constitute a key LTL group.

2 Connectance was calculated from the “recent state model” which is balanced for the year 2000.
3 Calculated using the starting conditions of the model.

There are few possible areas where further examination may improve protocols for classifying key LTL species and determining the utility of existing models for evaluating ecosystem impacts of fisheries.

- As mentioned by Essington and Plagányi (2013), estimates of connectance are dependent on food web structure, and SURF index thresholds set using simpler models may not be reasonable to use with more complex food web models. Since two more complex food web models have been developed for the California Current since the original report, the California Current would be a good ecosystem to use to see how these thresholds compare.
- Aggregation of different ages and/or sizes may have similar impacts on SURF index values as aggregating LTL species into groups (Essington and Plagányi, 2013). Here only one model has been evaluated to see whether the SURF index is affected, but these effects should be explored more thoroughly. In ecosystem models with higher complexity, that complexity should be included in the evaluation of Filter 1 as well as Filter 2.
- As model complexity increases, indications of "wasp-waistedness" may also be harder to find. For example, the most recent Ecopath model for the California Current has high connectance of groups of forage species but not certain species (Koehn *et al.*, 2016).

In cases where key LTL status needs to be assessed for freshwater stocks, additional investigation will be required before similar methodology for assessing whether a stock should be classified as LTL. This is largely because of differences in food web structure and function in freshwater as compared to marine ecosystems. Some of these differences include:

- Differences in species richness between marine and freshwater ecosystems, which will likely influence where cutoffs for "key-ness" are indicated
- Differences in food web structure based on ecosystem size (e.g., lake size)
- Influences of human activities and landscape ecology on freshwater food web structure and function, which will influence cutoffs and the ability to assess the influence of addition impacts (i.e., fishing LTL species) on the food web.

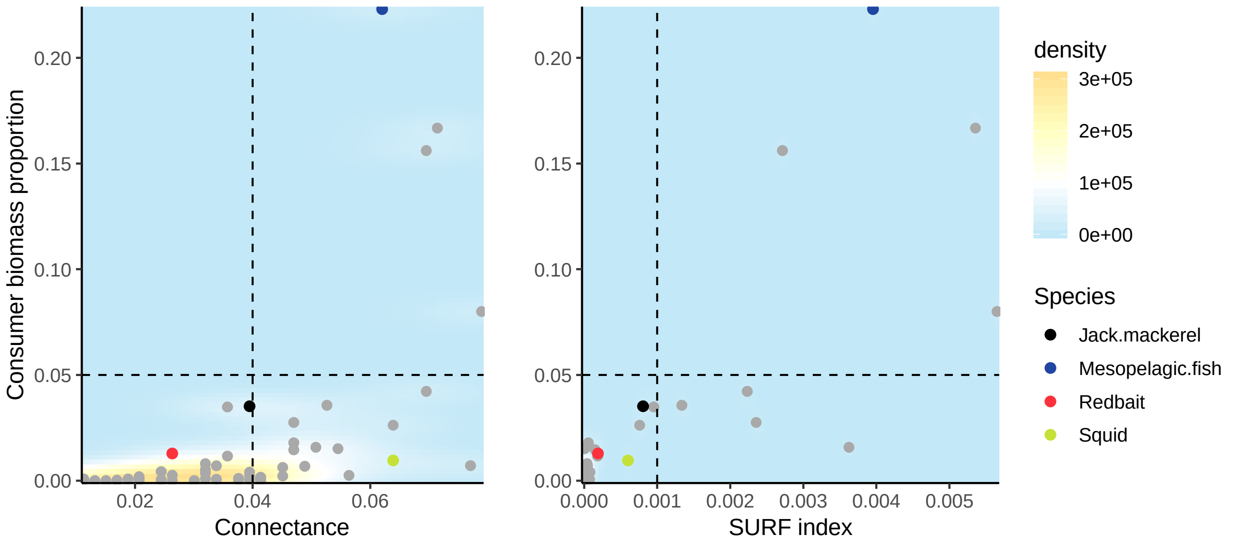

Figure 1. Proportional connectance, scaled SURF index, and consumer biomass proportion for the Ecopath with Ecosim model for the South Australian bight (Bulman et al., 2006), with forage species shown as colored points. Grey points each represent one species in the ecosystem. Dotted horizontal and vertical lines represent the thresholds for determining "keyness" according to Smith et al. (2011) and the MSC Fisheries Standard v2.01 (Connectance < 0.04 and SURF index < 0.001 both indicate a non-key LTL stock).

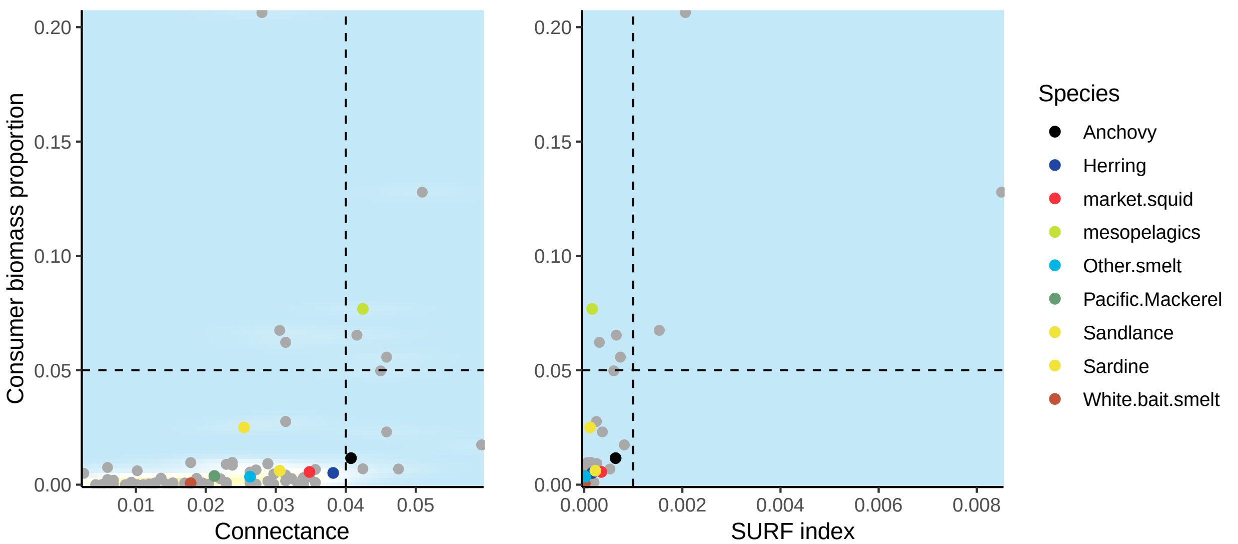

Figure 2. Proportional connectance, SURF index, and consumer biomass proportion for the Ecopath with Ecosim model for the California current based on the Ecopath model by Koehn et al. (2016). Grey points each represent one species in the ecosystem; low trophic level species are shown as colored points. Dotted lines show thresholds for consideration as key LTL species as in Figure 1.

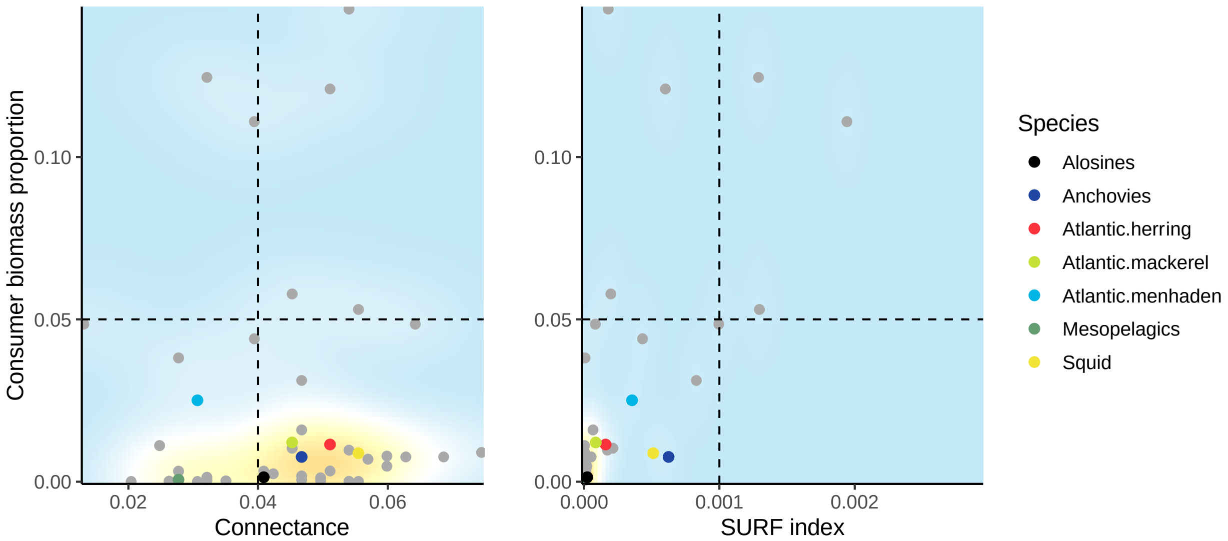

Figure 3. Proportional connectance, SURF index, and consumer biomass proportion $\left(\frac{B_{LTL}}{B_{consumers}}\right)$ for Atlantic menhaden, using on the Ecopath with Ecosim model from Buchheister et al. (2017). Grey points each represent one species in the ecosystem; low trophic level species are shown as colored points. Dotted lines show thresholds for consideration as key LTL species as in Figure 1.

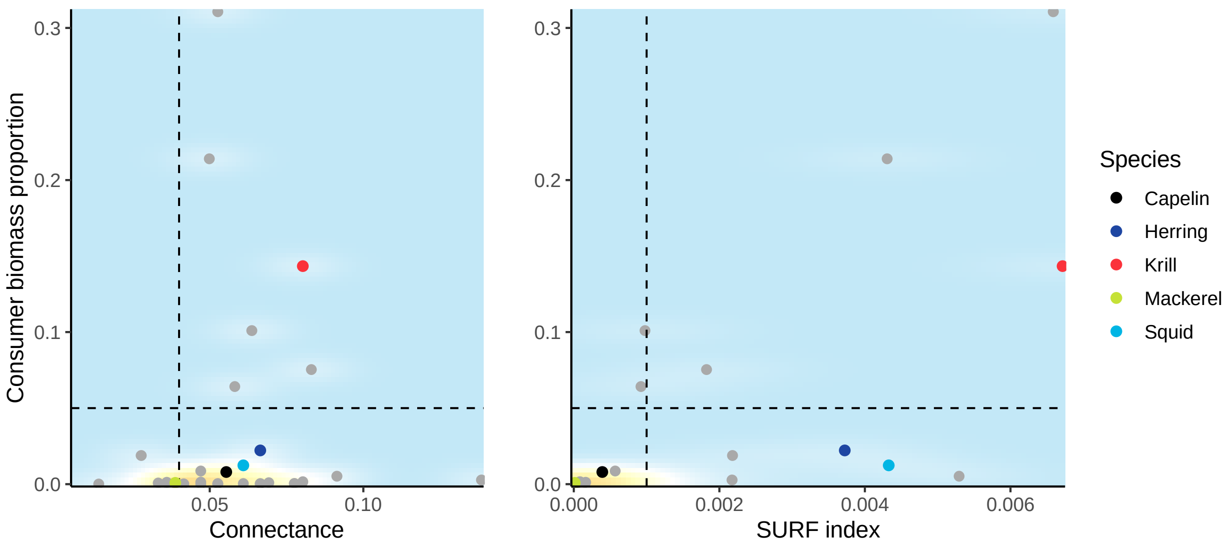

Figure 4. Proportional connectance, SURF index, and consumer biomass proportion for the Ecopath with Ecosim model for Barents Sea capelin on the Ecopath model by Skaret & Pitcher (2016), with forage species shown as colored points. Grey points each represent one species in the ecosystem. Dotted lines show thresholds for consideration as key LTL species as in Figure 1.

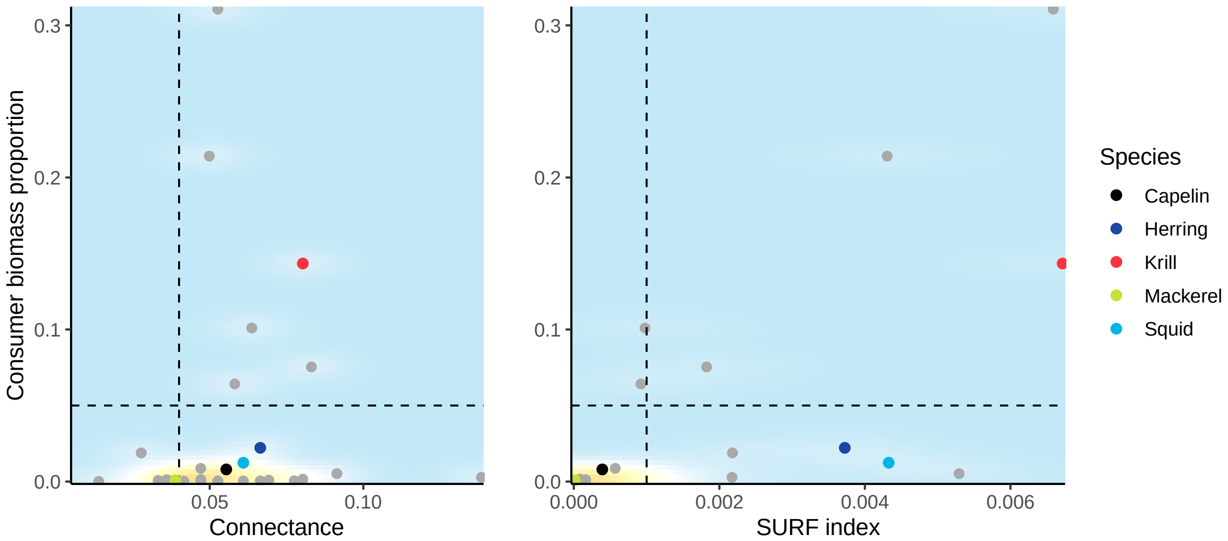

Figure 5. Proportional connectance, SURF index, and consumer biomass proportion for the Ecopath with Ecosim model for longfin squid from the Ecopath model used by Gasalla et al. (2010), with forage species shown as colored points. Grey points each represent one species in the ecosystem. Dotted lines show thresholds for consideration as key LTL species as in Figure 1. This model is based on a model originally published in 2004 (Gasalla and Rossi-Wongtschowski, 2004).

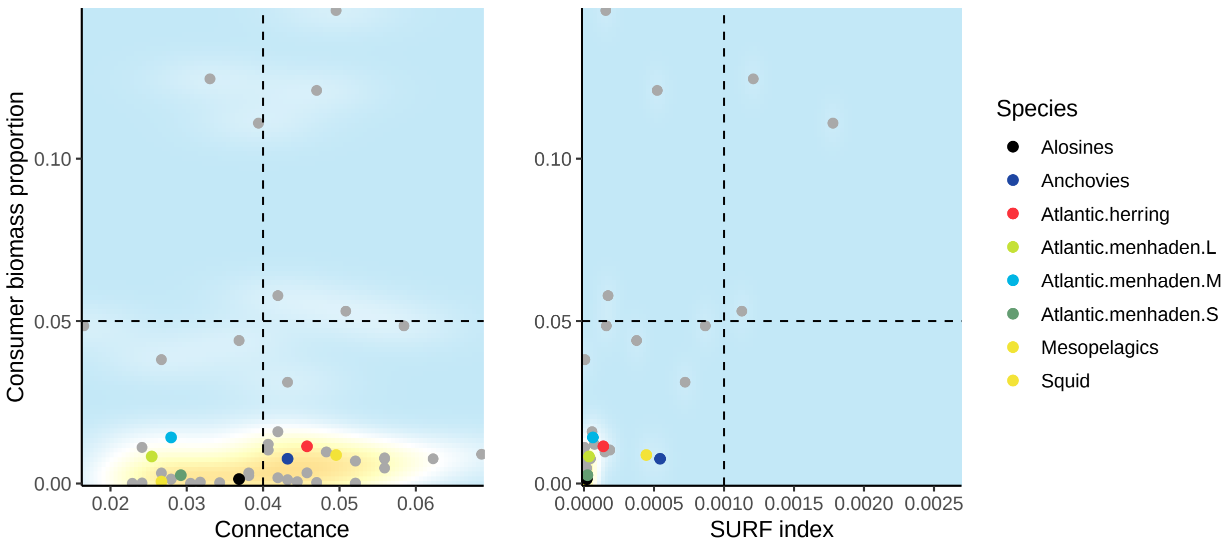

Figure 6. Proportional connectance, SURF index, and consumer biomass proportion for Atlantic menhaden when menhaden of different sizes are not aggregated into one group.

Appendix A: Models evaluated in this report

California current sardine

Scoring for new ecosystem models for California Current sardine. An updated Ecopath model (Koehn *et al.*, 2016), a MICE model (Punt *et al.*, 2016), and an Atlantis model (Kaplan *et al.*, 2017; Marshall *et al.*, 2017) have been developed since Essington and Plaganyi (2013). The scores in the third column are based on a paper that synthesizes these recent models (Kaplan *et al.*, 2019), particularly the MICE and Atlantis models. Kaplan et al. (2019) assess many of the criteria included below, so I refer readers to that paper for more detailed explanations of the properties of each of these models.

	CA Current Sardine (old score; Field *et al.*, 2006)	**CA Current Sardine (new score; Koehn et al. 2016)**	**CA Current sardine (new score) - justification**	**CA current sardine (new score; Kaplan et al. 2019)**	**CA Current sardine (new score; Kaplan et al. 2019) - justification**
Type of model	Ecosim and Atlantis	Ecopath	--	Multi-model (Ecopath, MICE, Atlantis)	The Ecopath model in this comparison is Koehn et al. (Koehn *et al.*, 2016) from the previous column. This column focuses primarily on Atlantis and MICE.
Spatial coverage	1	1	Spatial extent covers (N Vancouver Island to Baja; greater coverage than two previous CA current Ecopath models)	1	All models involved cover the full CCLME. Atlantis and MICE models extend further out into the ocean to cover the full EEZ, and Atlantis has much higher spatial resolution than the MICE model.
Time period	2	1	Data are from 2000-2014; model is a snapshot	1	MICE model contains parameters estimated from a fit to stock-recruit data for sardine from 1984-2008) but conclusions about ecosystem effects are from 2000-year projections (50

					replicates) starting at unfished equilibrium; Atlantis model runs starting in 2013 (model initialization) for 50 years
Low trophic level detail	1	2	All forage species are grouped to species level except for a smelt group that includes all osmerids except for whitebait smelt. No age structure is included in the model.	1/2 (1 for MICE, 2 for Atlantis)	MICE model has age structure for the LTL species (prey groups are sardine, anchovy, ‘other forage’ and ‘other prey’). Atlantis has sardine, anchovy, and herring at species level but other LTL species are aggregated into “other forage”.
Predator detail	1	2	Predators represented by species (no age structure) (see Appendix B)	2	Atlantis model includes four predator functional groups not identified to the species level (pelagic feeding seabirds, baleen whales, CA sea lions, and halibut). MICE model only includes two predators, brown pelicans and CA sea lions.
Predator breadth (includes large pelagic fish, marine mammals, sea birds)	1	1	Pelagic fish, marine mammals, and sea birds represented at species level	2/1 (2 for MICE, 1 for Atlantis)	MICE model does not include any whales, or bird/mammal species besides brown pelican and sea lions. Atlantis model includes all predator groups.
Quality of trophic data	2	1	All diet studies used are from CA current. Predator diets from CA current predator diet database, Szobozslai et al.	1	Diets in MICE model are the same as in Koehn et al. (2016); in the MICE model they are the average over the 2000-yr simulation. Atlantis diets are different

			(2015); forage fish diets came from (Brodeur *et al.*, 1987; Emmett *et al.*, 2005; Miller, 2006); lower-trophic level diets came from Field (2004)		
Model publication	1	1	Peer reviewed publication (Ecological Modeling)	1	Both models published in peer-reviewed journals; MICE model is in Ecological Modelling and Atlantis model is in MEPS
Simulation (time dynamic?)	Yes	No	Ecopath model is a snapshot of ecosystem	Yes	Both models are used for projections
Fitted to data?	Yes	NA	Ecopath is not time dynamic	Yes	Both models fitted to data; MICE is fitted to CalCOFI data for sardine and anchovy recruits, as well as stock-recruit curves for both main LTL species. MICE was also fitted to catches from US and Mexico sardine fisheries; Atlantis is based
Type of stock data	1	NA	Same as above	1	Survey data used in both models for fitting the model; stock assessment data used for sardine in both models
Other data used in fitting	No	No	--		Stock –recruit data for anchovy and sardine;
Fitting includes dynamic environmental variables as inputs?	Yes	No	--	Yes	In Atlantis the model is driven by a ROMS model for the California Current; in the MICE model there is an

					environmental driver for recruitment of sardine
Quality of fit	NA	NA	No fit quality bc not fitted to time series data	1/2	MICE model fits to stock-recruit data and recruit time series are good (SR fits are given in Appendix A); Atlantis is not fitted to data as the MICE model is, but bases scenarios on outcomes from the fitted MICE model (Kaplan et al. 2019 *suppl.*)
Simulations conducted to look at forage fish dependency?	Yes	Yes	No dynamic simulations to explore fishing scenarios (but see Koehn *et al.*, 2017). Kaplan et al. (2019) calculate a value for the PREP equation from this model.	Yes	Both MICE and Atlantis models explore ecosystem impacts of increased fishing mortality on sardine and anchovy; by comparing fishing and non-fishing scenarios and including a range of potential sardine biomasses. Atlantis model compares among different levels of prey biomass but does not have uncertainty around these scenarios. See Kaplan et al. (2017)
Environmental drivers included	No	No	NA	Yes	MICE model uses environmental drivers for sardine and anchovy abundance; Atlantis is driven by a full ROMS model.
Account for uncertainty	3	1	Simulations include random sampling from different diet distributions (followed by a filtration step that selected only diet	Yes (MICE) / No (Atlantis)	MICE uses simulations to explore uncertainty in biological parameters; Atlantis is too computationally intensive to run enough

			proportions that led to a balanced model) to identify uncertainty in predator impacts		times to explore uncertainty.
Represent local depletion?	No	No	There is no spatial resolution in the model so local depletion can't be represented	Yes	MICE model is spatially explicit and fishing is different in space because of US and Mexico fishing effort (but does not include scenarios with localized depletion); Atlantis explicitly accounts for local depletion (p 312)

Barents Sea capelin

	Barents sea capelin (old score) (Blanchard *et al.*, 2002)	**Barents sea capelin (new score; Skaret and Pitcher, 2016)**	**Barents sea capelin (new score) justification**
Type of model	Ecosim	Ecopath with Ecosim	--
Spatial coverage	1	1	Covers ICES areas I, IIa and IIb, which includes the Barents Sea (as previous model did) as well as the Norwegian Sea
Time period	3	3	More than 10 years old; not sure about ecosystem shifts during that time. Model compares a "past-state model" (1950-1954) and "recent state model" (1997-2001)
Low trophic level detail	2	1	LTL species separated by species and sometimes by age group
Predator detail	2	3	Seabirds are included but only split into penguins and "other seabirds" So some predators are split into different categories. Some predator species split into multiple age groups.
Predator breadth	1	1	Most predator guilds represented.

(includes large pelagic fish, marine mammals, sea birds)			
Quality of trophic data	1	1	Diet citations given are of studies conducted in the area (Dolgov, 2000) but not all diet studies are cited in the report, so not sure where all the data are coming from.
Model publication	2	2	Grey literature report in Fisken og Havet
Simulation (time dynamic?)	Yes	Yes	EwE is a time-dynamic model (shifts between 1950 and 2000)
Fitted to data?	No	No	Model was projected forward from 1950-2000 and model projections were compared with observed time series from VPA and acoustic surveys.
Type of stock data	--	2	Fitted to biomass for most fish species but no environmental data were used for fitting until after initial fitting. Some time series (e.g., capelin) are based on stomach content indices from their predators.
Other data used in fitting	--	Yes (primary production function)	Fluctuation in phytoplankton production was included "through a primary production forcing function" and improved fits when included in the model
Fitting includes dynamic environmental variables as inputs?	--	No	Figure 2 includes a "primary production function" that was generated by Ecosim but I don't understand what it is actually based on.
Quality of fit	--	2	No statistics involved in "fit"; just a comparison (Figure 4 in original report)
Simulations conducted to look at forage fish dependency?	No	No	--

Environmental drivers included	--	Yes (primary production function used to drive biomass in LTL species)	They used a primary production forcing function with Ecosim fits from 1950 to simulate primary production, then compared that to environmental covariates like NAO and SST. They provide R2 values for a regression between simulated and observed environmental variation but it does not appear that this is factored into a biomass fit.
Account for uncertainty	1	3	No information about uncertainty seems to be provided; the "sensitivity analysis" referred to in the report consists of adjusting the initial biomass until fishing pressure produces a change in biomass that the authors deem "adequate"
Represent local depletion?	No	No	--

Chesapeake Bay menhaden

	Old score (Christensen *et al.*, 2009)	**New score (Buchheister *et al.*, 2017)**	**New score justification**
Type of model	Ecosim	Ecopath with Ecosim	--
Spatial coverage	2	1	This study expands outside Chesapeake Bay to cover a large region that includes Mid- Atlantic Bight (MAB), southern New England (SNE), Georges Bank (GB), and the Gulf of Maine (GOM)
Time period	3	1	1982 - 2013
Low trophic level detail	1	3	Some small pelagics are grouped into an "other" category; all anchovy species are grouped as one. Age structure in menhaden averaged into groups from stock assessment (Appendix 1): ages groups into "stanzas" (multiple years per stanza).
Predator detail	1	3	Some predators are all grouped together but all others are sorted into age stanzas

Predator breadth (includes large pelagic fish, marine mammals, sea birds)	2	1	Includes categories for nearshore piscivorous birds, sea birds, and marine mammals
Quality of trophic data	2	1	Diet data averaged from regional models
Model publication	2	1	Published in Marine and Coastal Fisheries (Buchheister *et al.*, 2017)
Simulation (time dynamic?)	Yes	Yes	Ecosim simulations
Fitted to data?	Yes	Yes	Fitted to time series of relative biomass and catch, and fishing mortality and fishing effort were used to drive the model
Type of stock data	1	1	Most of the stocks have survey data in the model
Other data used in fitting	No	No	The authors suggest that environmental factors can be used to drive changes in production, mortality, and other processes in the model
Fitting includes dynamic environmental variables as inputs?	Yes	No	No environmental variables in the model, though forcing with environmental variables is mentioned as a possibility
Quality of fit	[blank]	1	Model SSQ is not reported but data vs. model fits are shown in Figure 3 of Buchheister et al 2017 and look reasonable
Simulations conducted to look at forage fish dependency?	Yes		They do test how model SSQ is affected by different predator-prey vulnerabilities
Environmental drivers included	No	No	--

Account for uncertainty	3	2	Used Monte Carlo simulations to explore uncertainty in parameters, but no specific discussion of data pedigree and not sure if uncertainty / MC sims are included in the discussion.
Represent local depletion?	No	No	--

Lake Michigan (Great Lakes USA) alewife and rainbow smelt – new

This system and model are somewhat unusual for determining LTL status because the predators in this system (salmonids) are stocked. The authors conclude in the study that predation mortality historically influenced the abundance of alewife in the lake, which is corroborated by other studies in the same system. The authors propose that increases in predator abundance drove down alewife productivity, which in turn caused a mass mortality event of Chinook salmon in the 1980's. It is worth considering whether the LTL species characteristics observed in marine species can be applied to freshwater ecosystems.

	New score (Tsehaye *et al.*, 2014)	**New score justification**
Type of model	Multispecies statistical catch at age model (SCA) – age-structured	--
Spatial coverage	1	Model covers all of Lake Michigan
Time period	2	Model time period is 1962-2008
Low trophic level detail	2	Whole population model is age-structured including predators and prey; data for alewife and smelt are by age BUT other forage species lumped (rainbow smelt, bloater, deepwater sculpin and slimy sculpin all included as one group)
Predator detail	1	Age structure also for lake trout, Chinook salmon, coho salmon, brown trout, and steelhead from predator assessment models

Predator breadth (includes large pelagic fish, marine mammals, sea birds)	1	Predators in the model only include piscivorous fish, but it's likely that seabirds and mammals are not significant predators in this ecosystem
Quality of trophic data	1	Diet data is from assessments of predators carried out in the same area
Model publication	1	Published in CJFAS
Simulation (time dynamic?)	Yes	But not sure because there aren't simulations to test for predator dependence…
Fitted to data?	Yes	Bottom trawl and hydroacoustic survey data for the forage species; some parameters in the model were taken from estimates taken from predator assessments
Type of stock data	2	Survey data for predators and prey but no environmental data included in model fitting
Other data used in fitting	No	Some parameter estimates for predators (growth, starting abundance) were taken from predator assessments.
Fitting includes dynamic environmental variables as inputs?	No	No environmental variables included in model inputs
Quality of fit	1	Fits vary by age class; good fits for older alewife but model consistently predicts higher abundance than observed in more recent years. Fit of model to data is reported as mean absolute percent error. Model fits are stronger across ages for rainbow smelt.
Simulations conducted to look at forage fish dependency?	No	Fits were used to make conclusions about the influence of predator abundance on forage fish mortality, not the other way around
Environmental drivers included	No	Time-varying components were recruitment and natural mortality (=constant background M + varying predation M)

Account for uncertainty	1	Model explicitly includes observation error, and because it's a Bayesian model, posterior probability distributions for parameter estimates are available
Represent local depletion?	No	Model is not spatial and does not account for localized depletion

Australian redbait (Southern Australia) – new

The score for Australian redbait is based on a hypothetical redbait fishery introduced in Bulman et al. (2011). Bulman et al. (2011) mention the LTL groups of interest in the Southern Australian bight, which include "jack mackerel (EBS) or mackerel (Atlantis), small pelagic fishes (*Engraulis australis* and *Sardinops sagax*), mesopelagic fishes (primarily *Lampanyctodes hectoris* and *Diaphus danae*), squid (various species not deep oceanic) and krill (*Nyctiphanes australis*)." They also mention that redbait was an LTL species but Atlantis simulations did not yield realistic redbait population trajectories even under the status quo, so only the EwE model is evaluated here (Bulman *et al.*, 2011). This report also mentions the MSC LTL classification specifically (p. 53; Section 7.3).

	New score (Bulman *et al.*, 2011)	**New score justification**
Type of model	Ecopath with Ecosim (EwE)	--
Spatial coverage	2	EwE model covers East Bass Strait (EBS)
Time period	1994-2003	Original EBS Ecopath model was built in 1994. The EwE model is described in Bulman et al. (2006) and runs from 1994-2003 (section 6.1.1 in Bulman et al. 2011, section 5 in (Bulman *et al.*, 2006))
Low trophic level detail	3	LTL species of interest were represented at species level; others were presented as larger groups (.e.g, blue mackerel are part of a larger group of "pelagic medium invertebrate feeders")
Predator detail	3	Some predators represented by species and others (like yellowtail scad) are grouped into larger groups like "pelagic medium predators" (similar to LTL species)

Predator breadth (includes large pelagic fish, marine mammals, sea birds)	1	Marine mammals, birds, and predatory fish are all included in the EBS model
Quality of trophic data	1	Diet data are from Southern Australia (some may be from other parts of Australia)
Model publication	2	Published as CSIRO report
Simulation (time dynamic?)	Yes	--
Fitted to data?	Yes	Fitted to abundance and catch data from EBS (which were updated since the original EwE model; Bulman et al. 2006)
Type of stock data	1	Catches and survey data from Southern Australia
Other data used in fitting	No	Model was fitted to CPUE time series, effort, and biomass but not environmental data.
Fitting includes dynamic environmental variables as inputs?	Yes	Environmental indices were used to "force" the model. In some simulations, the model was made so that it estimated its own primary productivity. Different primary productivity forcing functions were compared for fit using sum of squares (Bulman et al. 2006). Model was fitted using the same methods as Shannon et al. (2008)
Quality of fit	NA	NA
Simulations conducted to look at forage fish dependency?	Yes	Simulated changes in a hypothetical redbait fishery- biomass of redbait is real but the simulated catches were based on modifying data from the Tasmanian fishery to include higher catches. The species whose diets and preducitiy were modified to balance the modified model are described in Bulman et al. (2011), section 6.1.2.
Environmental drivers included	Yes	A few different environmental indices were used to drive the model and explore vulnerabilities. The primary production forcing function used is described in Bulman et al. (2006).
Account for uncertainty	2	Parameter uncertainty is addressed as a future step in the process. It is acknowledged in the discussion but there was not quantitative assessment of uncertainty.
Represent local depletion?	No	No spatial information included in the model. Authors mention that an Ecospace layer is available for the same model if needed, but that wasn't used in Bulman et al.'s analysis.

Brazilian long-finned squid (Southern Brazil bight) – new

This stock is unique because Gasalla et al. (2010) examine long-finned squid as both a key predator and key prey. Thus, the qualifications about detail in the predator and prey parts of the model are conflicted. For now, the “predator detail” part of the qualification is assumed to be the predators of squid (Bryde’s whales, etc.). The citation in the scope is Gasalla et al. 2010 but this paper seems to use an update to a model originally made by Gasalla (2008), published in an EU-INCOFISH final report that is not publicly available. The diet matrix and starting biomass for the original model are based on a model originally published in 2004 (Gasalla and Rossi-Wongtschowski, 2004), which was modified by Gasalla (2008). The scores here are based on the more recent publication, and the plot and SURF index calculations above are based on the original 2004 model.

	New score (Gasalla et al. 2010)	**New score justification**
Type of model	Ecopath with Ecosim*	* Seems like only the balanced model was used in actual analysis; so functionally it might be more like an Ecopath model
Spatial coverage	2	Squid are exploited from 22-28˚S and the data in the model are collected between 23-27˚S so the study covers a slightly smaller area than the fishery
Time period	2/3	Network model representing ecosystem in 2001 was updated with values based on new data collected in 2002-2003. Thus, all data is >10 years old and it is unknown whether there has been an ecosystem shift since then.
Low trophic level detail	2	The model includes squid (which are both LTL and predator, in this paper) by size structure (no age structure).
Predator detail		This score is based on the predators of squid, even though the paper counts squid as a key predator of several other species including other forage species
Predator breadth (includes large pelagic fish, marine mammals, sea birds)	1	Seabirds, marine mammals, and predatory fish included in model
Quality of trophic data	1	Stomach contents are from samples collected in the study area

Model publication	1	Published in ICES Journal of Marine Science
Simulation (time dynamic?)	Yes	--
Fitted to data?	Yes	The original model includes catch data and biomass (Gasalla and Rossi-Wongtschowski, 2004)
Type of stock data	3	Abundance and squid gut contents come from sampling from vessels targeting pink shrimp (i.e., there is no survey designed for squid or their predators specifically) – may be updated after I get original publication.
Other data used in fitting	No	--
Fitting includes dynamic environmental variables as inputs?	No	No environmental variables included – may be updated after I get original publication
Quality of fit	NA (not fitted to time series data)	--
Simulations conducted to look at forage fish dependency?	No	Not specifically but they calculated a "keystoneness index" (Libralato *et al.*, 2006), which is intended to provide a measure of how sensitive the food web would be to changes in squid biomass
Environmental drivers included	No	No environmental variables included in the model – may be updated after I get original publication.
Account for uncertainty	3	Parameter uncertainty not discussed (may be updated).
Represent local depletion?	No	--

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