

Supplementary Material

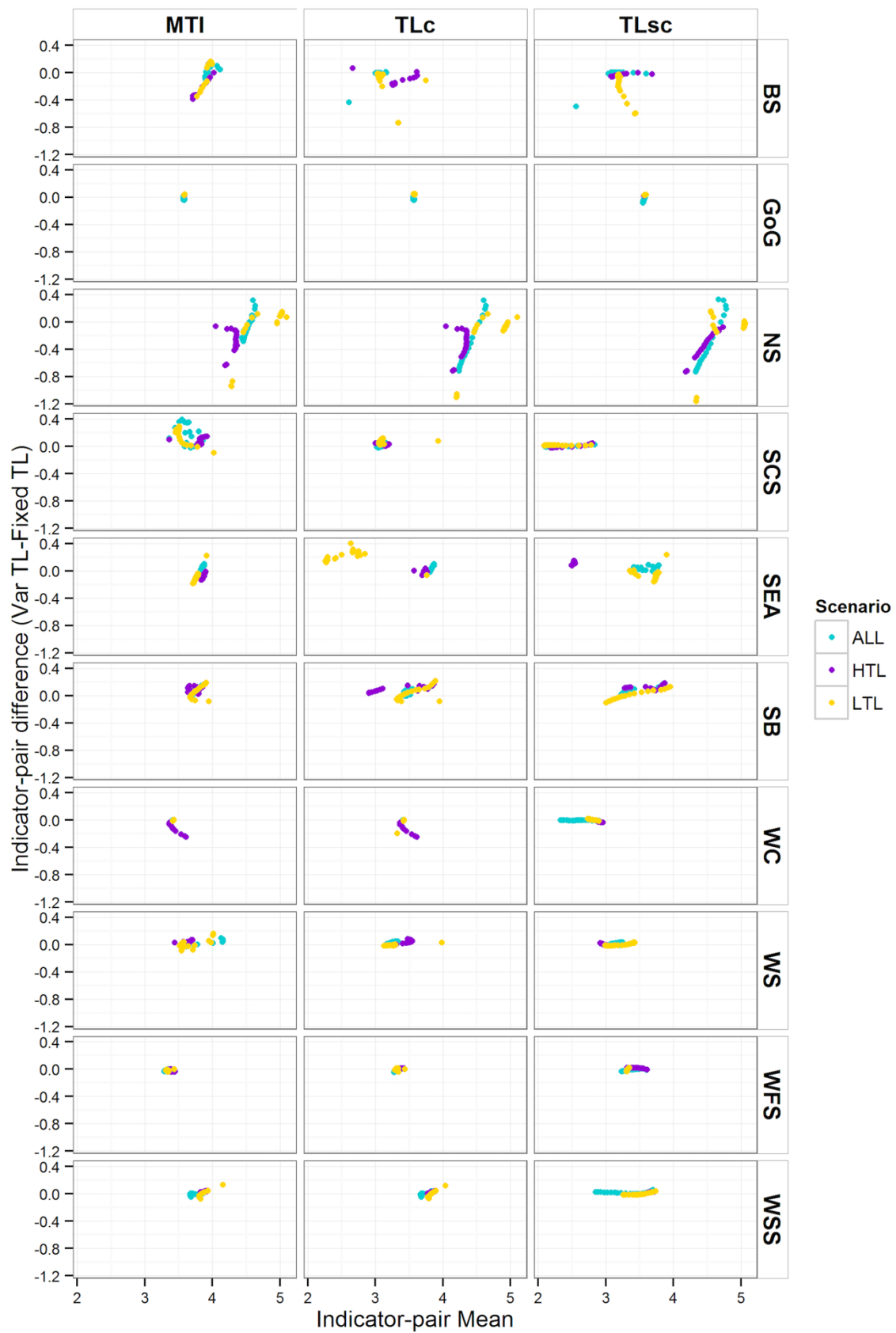


Figure S1. Standardised differences in variable and fixed TL-based indicators across modelled ecosystems and indicators (variable TL-based indicator – fixed TL-based indicator), with data points

coloured by fishing scenario (LTL, HTL and ALL). See Methods for a description of the three fishing scenarios. MTI = mean trophic index, TL_c = trophic level of the landed catch, TL_{sc} = trophic level of the surveyed community. BS = Black Sea, GoG = Gulf of Gabes, NS = North Sea, SCS = South Catalan Sea, SEA = South-east Australia, SB = Southern Benguela, WC = West coast of Canada, WS = West coast of Scotland, WFS = West Florida Shelf and WSS = Western Scotian Shelf.

Table S1. Description of the models run in this study. The specifications correspond to the versions and ecosystem applications of this study. Other characteristics or options exist in other case studies.

	Atlantis	Ecopath with Ecosim (EwE)	OSMOSE	Multispecies Size Spectrum
Case studies in this paper (contact author)	South East Australia (E.A. Fulton)	Southern Benguela (L.J. Shannon), Western Scotian shelf (A. Bundy), South Catalan Sea (M. Coll), West Coast Scotland (J.J. Heymans), Black Sea (E. Akoglu)	West Coast of Canada (C. Fu), Gulf of Gabes (G. Halouani), West Florida Shelf (A. Grüss)	North Sea (J. Houle)
Summary description	Whole of ecosystem model from hydrodynamic conditions to food web and human users	Mass-balance model of marine food webs that accounts for the flow of biomass between trophic groups.	Size-structured and multispecies individual-based model of fish community dynamics. Its current structure embeds the two-way coupling with hydrodynamic and biogeochemical models or the forcing by fields of plankton and benthos biomasses (end-to-end model).	Multispecies model describing the flux of fish biomass along size classes
Key features	Modular (multiple options per process). Includes age structure and major ecological processes such as full life history closure, gape-limited predation, habitats, movement, biogeochemical nutrient cycling and a range of effort allocation options.	Ecosim is a dynamic model describing the predator-prey interactions from primary producers to top predators.	Trophic interactions are size-based, so the modelled food webs are variable. The whole life cycle of the species is modelled (migration, food-dependent growth, reproduction and mortality), with tracking of all life stages (from eggs to terminal age) in space and time. The model provides size-, age-, species- and trophic level-based indicators in output.	Trophic interactions are size-based and the dynamics of multiple fish species is modelled.
Currency	Nitrogen	Biomass	Individual biomass and numbers	Biomass
Spatial structure	3-dimensional, polygons	0-dimensional	2-dimensional, regular grid, the resolution is flexible, typically of 1/10th of degree. The vertical distribution of fish is handled through a matrix of accessibility.	0-dimensional
Time step	12 hourly	Monthly	Weekly, fortnightly or monthly, depending on the application	Monthly

Species/ Trophic groups	~ 60 species/functional groups. Vertebrate groups (and key commercial species) are represented with full age structure (following condition and number of individuals per age class) and invertebrates as biomass pools.	~ 50 species/functional groups All taxonomic groups can be included as biomass pools or multiple ontogenetic groups (multistanza) (mainly for commercial species with larger data availability). Typically resolved to a mix of functional groups and key species	~10-15 pelagic-demersal and benthic fish and invertebrate species with explicit individual-based, size-based and whole life cycle processes. ~5-10 plankton and low-trophic level benthic groups linked to the rest of the food web by biomass fluxes.	12 size-structured fish species
Parameteri- Sation	Depends on configuration, but extensive parameterisation is typically required. Also needs physical drivers and initial system state.	Main parameters available through scientific surveys and stock assessments, fisheries statistics and ecological studies. Needs time series of biomass and fishing effort/mortality, catches and ideally environmental drivers in Ecosim to fit the model to data.	Life history traits (growth, reproduction), predator to prey size ratios, fish spatial distribution data. Data needs for calibrating the model: biomass indices and commercial catch data.	Life history traits, predator to prey size ratios.
Age structure	Variable. For SE Australia age structured groups track annual age classes for aging but all other ecological processes are applied to 10 life stanzas per species/functional group (with annual age classes aggregated within the stanzas)	"Multistanza" age classes for some species/functional groups	Fish age is tracked; discretization depends on time step	No – but each species/functional groups is fully size structured
Functional response	Holling Type I, II, III, IV ratio dependent, Hasley-Varley and Crowley-Martin	Ecosim specific functional response based on "Foraging Arena"	Functional response is not imposed. Emerges from individual interactions and maximum ingestion rate	Holling Type II
Repro- Duction	Wide range including Ricker, Beverton-Holt, fixed #/adult, random, plankton dependent, forced.	Intrinsic population growth rate for non-stanza groups; recruitment emerges from growth parameters set for feeding behavior for multi-stanza groups.	Based on fecundity and spawning stock biomass, which depends on predation efficiency. Recruitment is an emergent property of the model.	Beverton-Holt stock-recruitment
Movement/ migration	Foraging and seasonal migration	No movement in the case studies here, except for large migratory species in some case studies (South Catalan Sea)	Ontogenetic and seasonal migration; random movement mimicking foraging movements.	no movement

Fishing	Spatial: Fleets' catch, effort, or fishing mortality rates	Fleets' catch, effort, or fishing mortality rates	Fishing mortality rates, knife-edge size selectivity	Fishing effort, size selectivity
Coupling with ocean model	Yes	No	Yes (Gulf of Gabes)	No
References	Fulton et al. 2011	Christensen and Walters 2004 www.ecopath.org	Shin and Cury 2004, Travers-Trolet <i>et al.</i> 2014, www.osmose-model.org	Hartvig et al. 2011

References

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Table S2. Species/groups considered in each ecosystem model and fishing scenarios targeting species/groups.

Modelled ecosystem	Name	Fishing scenario
Black Sea	Atlantic bonito	HTL/ALL
	Bluefish	HTL/ALL
	Atlantic mackerel	HTL/ALL
	Whiting	HTL/ALL
	Turbot	HTL/ALL
	Red mullet	ALL
	Spiny dogfish	HTL/ALL
	Horse mackerel	ALL
	Shad	ALL
	Sprat	LTL/ALL
	Anchovy	LTL/ALL
Gulf of Gabes	<i>Octopus vulgaris</i>	ALL
	<i>Penaeus kerathurus</i>	ALL
	<i>Metapenaeus monoceros</i>	ALL
	<i>Trachurus trachurus</i>	ALL
	<i>Sardina pilchardus</i>	LTL/ALL
	<i>Sardinella aurita</i>	LTL/ALL
	<i>Engraulis encrasicolus</i>	LTL/ALL
	<i>Diplodus annularis</i>	ALL
	<i>Mustelus mustelus</i>	HTL/ALL
	<i>Merluccius merluccius</i>	HTL/ALL
	<i>Pagellus erythrinus</i>	ALL
North Sea	Sprat	LTL/ALL
	Sandeel	LTL/ALL
	Norway Pout	LTL/ALL
	Herring	LTL/ALL
	Dab	HTL/ALL
	Whiting	HTL/ALL
	Sole	HTL/ALL
	Gurnard	HTL/ALL
	Plaice	HTL/ALL
	Haddock	HTL/ALL
	Cod	HTL/ALL
	Saithe	HTL/ALL
South Catalan Sea	Shrimps	LTL/ALL
	Crabs	LTL/ALL
	Norway lobster	LTL/ALL
	Benthic invertebrates	
	Benthic cephalopods	LTL/ALL
	Benthopelagic cephalopods	HTL/ALL
	Mulletts	LTL/ALL
	Conger eel	HTL/ALL
	Anglerfish	HTL/ALL
	Flatfishes	LTL/ALL
	Poor cod	LTL/ALL
	Juvenile hake	LTL/ALL
	Adult hake	HTL/ALL
	Blue whiting	LTL/ALL
	Demersal fishes (1)	LTL/ALL
	Demersal fishes (2)	
	Demersal fishes (3)	HTL/ALL
	Demersal sharks	HTL/ALL
	Benthopelagic fishes	
	European anchovy	LTL/ALL
	Sardine adults	LTL/ALL
	Other small pelagic fishes	LTL/ALL
	Horse mackerel	LTL/ALL
	Mackerel	LTL/ALL
	Atlantic bonito	HTL/ALL
	Swordfish and Tuna	HTL/ALL
	Loggerhead turtles	
	Audouin's gull	
	Other sea birds	
	Dolphins	

	Crustaceans	LTL/ALL
	Cephalopod	LTL/ALL
	Scallops	LTL/ALL
West Florida Shelf	King mackerel	HTL/ALL
	Amberjacks	HTL/ALL
	Red grouper	HTL/ALL
	Gag grouper	HTL/ALL
	Red snapper	HTL/ALL
	Sardine Herring Scad Complex	LTL/ALL
	Anchovies and Silversides	LTL/ALL
	Coastal omnivores	LTL/ALL
	Reef carnivores	ALL
	Reef omnivores	ALL
Western Scotian Shelf	Shrimps	ALL
	Large crabs	ALL
	Sharks	HTL/ALL
	Large pelagic	HTL/ALL
	Cod 1-3 yr	HTL/ALL
	Cod 4-6 yr	HTL/ALL
	Cod 7+ yr	HTL/ALL
	Silver Hake <25 cm	ALL
	Silver Hake 25-31 cm	ALL
	Silver Hake 31+ cm	HTL/ALL
	Halibut <46 cm	ALL
	Halibut 46-81 cm	HTL/ALL
	Halibut 82+ cm	HTL/ALL
	Pollock <49 cm	ALL
	Pollock 49+ cm	HTL/ALL
	Demersal piscivores	HTL/ALL
	Large benthivores	ALL
	Skates <49 cm	ALL
	Skates 49+ cm	ALL
	Dogfish	HTL/ALL
	Redfish	ALL
	American plaice 26+ cm	ALL
	Flounders	ALL
	Haddock <3 yr	ALL
	Haddock 3+ yr	ALL
	Longhorn sculpin <25 cm	ALL
	Longhorn sculpin 25+ cm	ALL
	Herring <4 yr	LTL/ALL
	Herring 4+ yr	LTL/ALL
	Other pelagic	LTL/ALL
	Mackerel	LTL/ALL
	Mesopelagic	
	Small-medium benthivores	
	Squids	ALL
	Lobster	ALL
	Large crabs	
	Small crabs	
	Shrimps	
	Scallop	ALL

Table S3. Spearman's correlation coefficients between trophic level-based indicators (trophic level of the surveyed community (TL_{sc}), trophic level of the landed catch (TL_c) and mean trophic index (MTI)) and fishing pressure (Fmsy multiplier), across three fishing scenarios (LTL, HTL and ALL), when fixed trophic levels (TLs) (Fixed) and variable TLs (Var) are used to calculate TL-based indicators. Bold values indicate significant correlations ($p < 0.05$) with dark blue cells = negative correlations, light blue cells = positive correlations. Note that no correlation coefficient values are provided for the West coast of Canada ecosystem for the TL_c and MTI indicators, under the LTL fishing scenario, when fixed TL values are used. In this case study only one species is landed (Pacific Herring, fixed TL = 3.418) resulting in static indicator values (TL_c and MTI) with increasing fishing pressure, and therefore no possible correlations. See Methods for a description of the three fishing scenarios.

Ecosystem	Scenario	MTI		TL _c		TL _{sc}	
		TL Type	Correlation coefficient	TL Type	Correlation coefficient	TL Type	Correlation coefficient
Black Sea	LTL	Fixed	-0.9699	Fixed	0.4887	Fixed	0.9835
	LTL	Var	0.3203	Var	-0.9444	Var	-0.6075
	HTL	Fixed	-0.7003	Fixed	-0.3744	Fixed	-0.5564
	HTL	Var	-0.6662	Var	-0.5474	Var	-0.5609
	ALL	Fixed	-0.3869	Fixed	-0.7298	Fixed	-0.5053
	ALL	Var	0.4027	Var	-0.7368	Var	-0.4917
Gulf of Gabes	LTL	Fixed	-0.7893	Fixed	0.5113	Fixed	0.9895
	LTL	Var	0.8090	Var	0.7303	Var	0.9850
	HTL	Fixed	-0.3203	Fixed	-0.4737	Fixed	-0.8845
	HTL	Var	-0.6707	Var	-0.6130	Var	-0.9970
	ALL	Fixed	0.9982	Fixed	1.0000	Fixed	0.9850
	ALL	Var	-0.4526	Var	-0.5246	Var	-0.9985
North Sea	LTL	Fixed	0.1158	Fixed	0.1158	Fixed	0.6511
	LTL	Var	-0.1684	Var	-0.3338	Var	-0.1248
	HTL	Fixed	0.8466	Fixed	0.8466	Fixed	-1.0000
	HTL	Var	-0.6526	Var	-0.6842	Var	-0.9985
	ALL	Fixed	0.9140	Fixed	0.9140	Fixed	0.3098
	ALL	Var	-0.6772	Var	-1.0000	Var	-0.9910
South Catalan Sea	LTL	Fixed	-0.9459	Fixed	-0.1594	Fixed	-0.9985
	LTL	Var	-0.4301	Var	0.4767	Var	-1.0000
	HTL	Fixed	0.5654	Fixed	0.9038	Fixed	-1.0000
	HTL	Var	0.7865	Var	0.9128	Var	-1.0000
	ALL	Fixed	-0.6035	Fixed	-0.5649	Fixed	-0.8962
	ALL	Var	-0.0930	Var	-0.4947	Var	-0.8496
South-east Australia	LTL	Fixed	0.2632	Fixed	0.6917	Fixed	0.9820
	LTL	Var	-0.1820	Var	0.6421	Var	0.5714
	HTL	Fixed	-0.6677	Fixed	-0.5444	Fixed	-0.9143
	HTL	Var	0.0887	Var	-0.1925	Var	-0.5068
	ALL	Fixed	-0.3545	Fixed	0.9877	Fixed	0.2135
	ALL	Var	0.3860	Var	0.4912	Var	0.3203
Southern Benguela	LTL	Fixed	0.3579	Fixed	0.6436	Fixed	1.0000
	LTL	Var	0.7489	Var	0.7955	Var	1.0000
	HTL	Fixed	0.0241	Fixed	-0.9639	Fixed	-1.0000
	HTL	Var	-0.3699	Var	-0.9564	Var	-1.0000
	ALL	Fixed	-0.9877	Fixed	-0.5281	Fixed	-0.3128
	ALL	Var	-0.0474	Var	-0.1333	Var	-0.1368

		MTI		TLc		TLsc	
Ecosystem	Scenario	TL Type	Correlation coefficient	TL Type	Correlation coefficient	TL Type	Correlation coefficient
West coast of Canada	LTL	Fixed	NA	Fixed	NA	Fixed	-0.9609
	LTL	Var	0.0733	Var	-0.0877	Var	-0.8992
	HTL	Fixed	1.0000	Fixed	1.0000	Fixed	0.9624
	HTL	Var	0.7386	Var	0.7386	Var	0.9083
	ALL	Fixed	0.6860	Fixed	0.6860	Fixed	-1.0000
	ALL	Var	0.6702	Var	0.6702	Var	-0.9985
West coast of Scotland	LTL	Fixed	0.3098	Fixed	0.5023	Fixed	0.9850
	LTL	Var	0.4000	Var	0.4451	Var	0.9714
	HTL	Fixed	-0.2256	Fixed	-0.1774	Fixed	-1.0000
	HTL	Var	-0.3053	Var	0.0962	Var	-0.9895
	ALL	Fixed	0.7825	Fixed	0.7596	Fixed	0.7955
	ALL	Var	0.7526	Var	0.6947	Var	0.7398
West Florida Shelf	LTL	Fixed	0.0556	Fixed	0.4241	Fixed	0.2541
	LTL	Var	-0.3624	Var	0.0662	Var	-0.9925
	HTL	Fixed	-0.5444	Fixed	-0.4902	Fixed	-1.0000
	HTL	Var	-0.3308	Var	-0.3850	Var	-0.9985
	ALL	Fixed	-0.9930	Fixed	-0.4579	Fixed	-1.0000
	ALL	Var	-0.8281	Var	-0.9316	Var	-1.0000
Western Scotian Shelf	LTL	Fixed	0.0150	Fixed	-0.2903	Fixed	-1.0000
	LTL	Var	-0.8722	Var	-0.9038	Var	-1.0000
	HTL	Fixed	-0.7474	Fixed	-0.5188	Fixed	-0.9308
	HTL	Var	-0.4812	Var	-0.4617	Var	-0.9079
	ALL	Fixed	-0.9123	Fixed	-0.9000	Fixed	-1.0000
	ALL	Var	-1.0000	Var	-1.0000	Var	-1.0000