Appendix A. Supplementary data

Table A1. High-trophic-level (HTL) and low-trophic-level (LTL) species/taxa represented in the ecosystem models.

Ecosystem	Modelled HLT group species/taxa	Modelled LTL group species/taxa	Ecosystem model
Black Sea	Atlantic bonito, Bluefish, Atlantic mackerel, Whiting, Turbot, Red mullet, Spiny dogfish	Horse mackerel, Shad, Sprat, Anchovy	Ecopath with Ecosim
Gulf of Gabes	Mustelus mustelus, Merluccius merlucciu, Octopus vulgaris, Melicertus kerathurus, Metapenaeus monoceros, Trachurus trachurus,	Sardina pilchardus, Sardinella aurita, Engraulis encrasicolus, Diplodus annularisPagellus erythrinus	OSMOSE
North Sea	Dab, Whiting, Sole, Gurnard, Plaice, Haddock, Cod, Saithe	Sprat, Sandeel, Norway Pout, Herring	Size Spectrum
South Catalan Sea	Benthopelagic cephalopods, Conger eel, Anglerfish, Demersal fishes (3), Adult hake, Demersal sharks, Atlantic bonito, Swordfish and Tuna, Loggerhead turtles, Audouin's gull, Other sea birds, Dolphins	Shrimps, Crabs, Norway lobster, Benthic invertebrates, Benthic cephalopods, Mullets, Flatfishes, Poor cod, Juvenile hake, Blue whiting, Demersal fishes (1), Demersal fishes (2), Benthopelagic fishes, European anchovy, Sardine adults, Other small pelagic fishes, Horse mackerel, Mackerel	Ecopath with Ecosim
Southeastern Australian	Shallow Demersals, Flathead, Pink Ling, Trevalla, Gummy Shark, Small Pelagic Tuna, Demersal Shark, Dogfish, Grenadier, Pelagic Shark, Gulper Shark, Shallow Piscivores	Mackerel, Myctophids, Red Bait, Squid, Krill	Atlantis
Southern Benguela	Chub mackerel, Adult Horse mackerel, Snoek, Other large pelagics, Merluccius capensis, Merluccius paradoxus, Pelagicdemersals, Benthicdemersals, Pelagic Chondrichthyes, Benthic Chondrichthyes, Apex Chondrichthyes	Anchovy, Sardine, Redeye, Other small pelagics, Juvenile Horse mackerel, Mesopelagics, Cephalopods,	Ecopath with Ecosim
West coast Canada	Walleye pollock, Pacific cod, Lingcod, Spiny dogfish, Spotted ratfish, Harbour seal	Euphausiids, Shrimp, Pacific herring,	OSMOSE
Western Scotland	Cod mature, Haddock mature, Whiting mature, Pollock, Gurnards, Monkfish, Rays,Sharks, Large demersals,	Flatfish, Other small fish, Mackerel, Horse mackerel, Blue whiting, Herring, Norway pout, Sandeel, Sprat, Nephrops, Lobster, Edible crab, Crustaceans, Cephalopod, Scallops	Ecopath with Ecosim
West Florida Shelf	King mackerel, Amberjacks, Red grouper, Gag grouper, Red snapper,	Sardine Herring Scad Complex, Anchovies and Silversides, Coastal omnivores, Reef carnivores, Reef omnivores, Shrimps, Large crabs	OSMOSE
Western Scotian Shelf	Sharks, Cod, Silver Hake, Halibut, Pollock, Demerdal piscivores, Large benthivores, Skates, Dogfish, Redfish, American plaice, Flounders, Haddock adult	Haddock young, Longhorn sculpin, Herring, Other pelagic, Mackerel, Mesopelagic, Small-medium benthivores, Squids, Lobster, Crabs, Shrimps, Scallop	Ecopath with Ecosim

Table A2. Descriptions of the ecosystem modelling frameworks applied in the study.

	Atlantis	Ecopath with Ecosim	OSMOSE	Size Spectrum
Summary description	Whole ecosystem model from hydrodynamic conditions to foodweb and human users	Mass-balance model of marine foodwebs that accounts for the flow of biomass between trophic groups.	Size-structured Individual-based model of fish community dynamics with coupling with hydrodynamic and biogeochemical models (end-to-end model).	Multispecies model describing the flux of biomass along size classes
Key features	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. Can include multiple stanzas representing different age classes.	The whole life cycle of the species is modelled (migration, food-dependent growth, reproduction and mortality) in space and time.	Trophic interactions are size-based and the dynamics of multiple focus fish species is modelled.
Currency	Nitrogen	Biomass	Individual biomass and numbers	Biomass
Spatial structure	2D, polygons	None	2D, regular grid. Vertical distribution of fish is handled through a matrix of accessibility.	None
Parameter-ization	Depends on configuration, but usually extensive parameterisation is required. Also needs physical drivers and initial system state.	Needs time series of abundance/biomass and/or fishing effort/mortality and ideally environmental drivers in Ecosim to fit the model to data.	Life history traits, predator to prey size ratios, fish spatial distribution data. Data needs for model calibration: biomass indices and commercial catch data	Life history traits, predator to prey size ratios
Age structure	Vertebrates: 10 age classes	"Multistanza" age classes for some species/functional groups	Fish age is tracked; discretization depends on time step.	No age structure, but each species/functional group is fully size structured
Functional response	Holling Type I,II,III, others	Function repsonse is an emergent property of Ecosim, based on the "Foraging Arena".	Functional response is not imposed. Predation emerges from individual interactions and maximum ingestion rate.	Holling Type II
Reproduction	Ricker, Beverton, fixed number per adult, others	Intrinsic population growth rate for non-stanza groups; recruitment emerges from fecundity and feeding behaviour for multi-stanza groups.	Based on fecundity and spawning stock biomass, recruitment emerges	Beverton-Holt stock-recruitment
Movement/ migration	Foraging and seasonal migration	No movement in the case studies here	Foraging and seasonal migration	No movement
Fishing	Spatial: Fleets' catch, effort, or fishing mortality rates	Fleets' catch, effort, or fishing mortality rates	Fishing mortality rates	Fishing effort, size selectivity

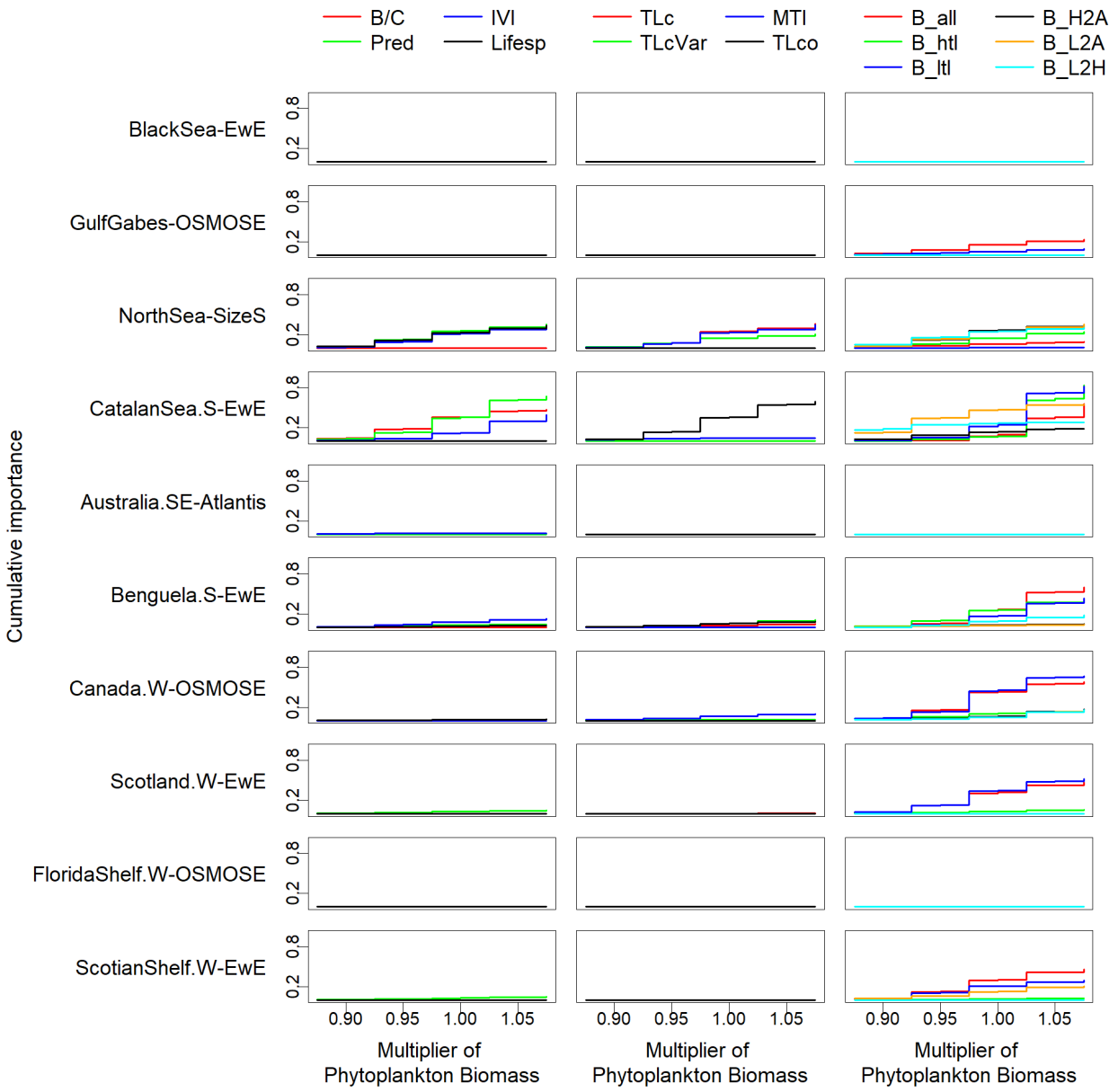

Fig. A1 Cumulative shifts (in R^2 units) in response to levels of primary productivity (multiplier of phytoplankton biomass) in ten marine ecosystems with first column for indicators B/C (biomass to fisheries catch ratio), Pred (proportion of predatory fish), IVI (mean intrinsic vulnerability), and Lifesp (mean life span); second column for TLc (mean trophic level TL of catch), TLcVar (mean TL of catch with variable TL), MTI (marine trophic index), and TLco (mean TL of fish community surveyed); and third column for B_all (biomass of all species), B_htl (biomass of high-trophic-level species), B_all (biomass of low-trophic-level species), B_H2A (the ratio of B_htl to B_all), B_L2A (the ratio of B_ltl to B_all), and B_L2H (the ratio of B_ltl to B_htl).

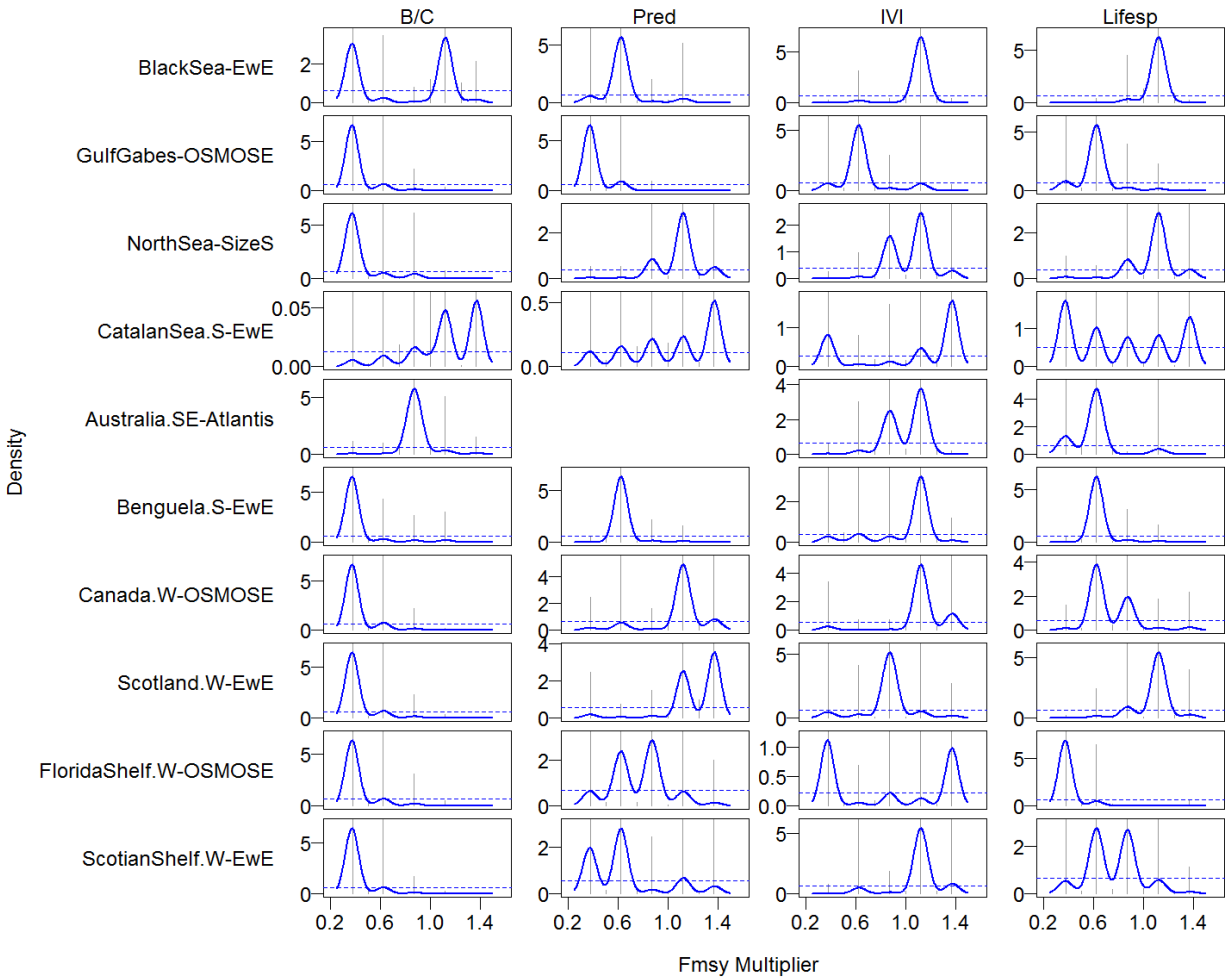

Fig. A2 Threshold shifts in the values of four indicators indicators (B/C: biomass to fisheries catch ratio, Pred: proportion of predatory fish, IVI: mean intrinsic vulnerability, and Lifesp: mean life span) along the gradient of fishing pressure under random change in primary productivity of standard deviation = 0.1. The dashed line indicates where the ratio of the density of split importance to the density of observed fishing pressure is 1; peaks above the dashed line suggest threshold values for the fishing pressure. Missing plots indicate failed convergence of the gradient forest model.

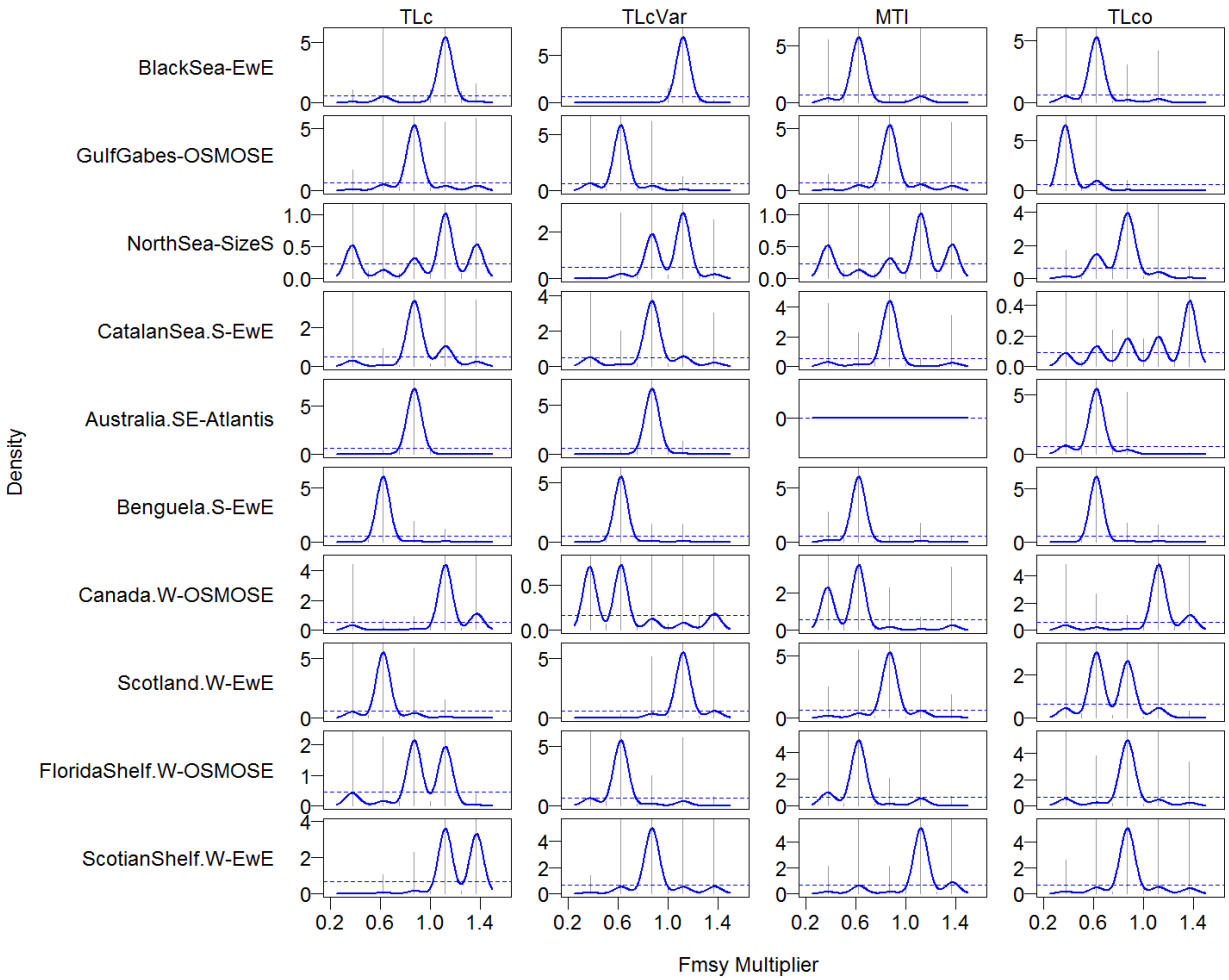

Fig. A3 Threshold shifts in the values of four trophic level (TL) based indicators (TLc: mean TL of catch, TLcVar: mean TL of catch with variable TL, MTI: marine trophic index, and TLco: mean TL of fish community surveyed) along the gradient of fishing pressure under randome change in primary productivity of standard deviation = 0.1.

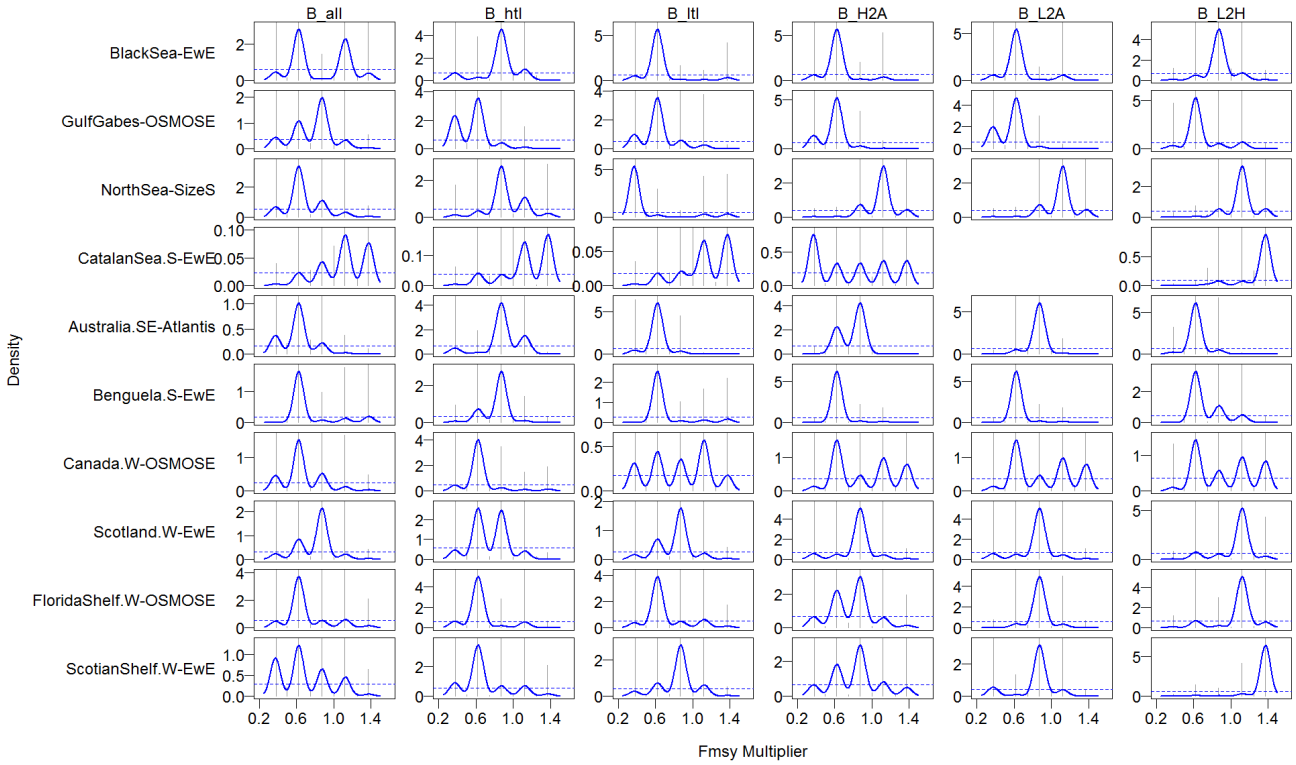

Fig. A4 Threshold shifts in the values of six biomass-based indicators (B_all: biomass of all species, B_htl: biomass of high-trophic-level species, B_all: biomass of low-trophic-level species, B_H2A: the ratio of B_htl to B_all, B_L2A: the ratio of B_ltl to B_all, and B_L2H: the ratio of B_ltl to B_htl) along the gradient of fishing pressure under random change in primary productivity of standard deviation = 0.1. The dashed line indicates where the ratio of the density of split importance to the density of observed fishing pressure is 1; peaks above the dashed line suggest threshold values for the fishing pressure. Missing plots indicate failed convergence of the gradient forest model.

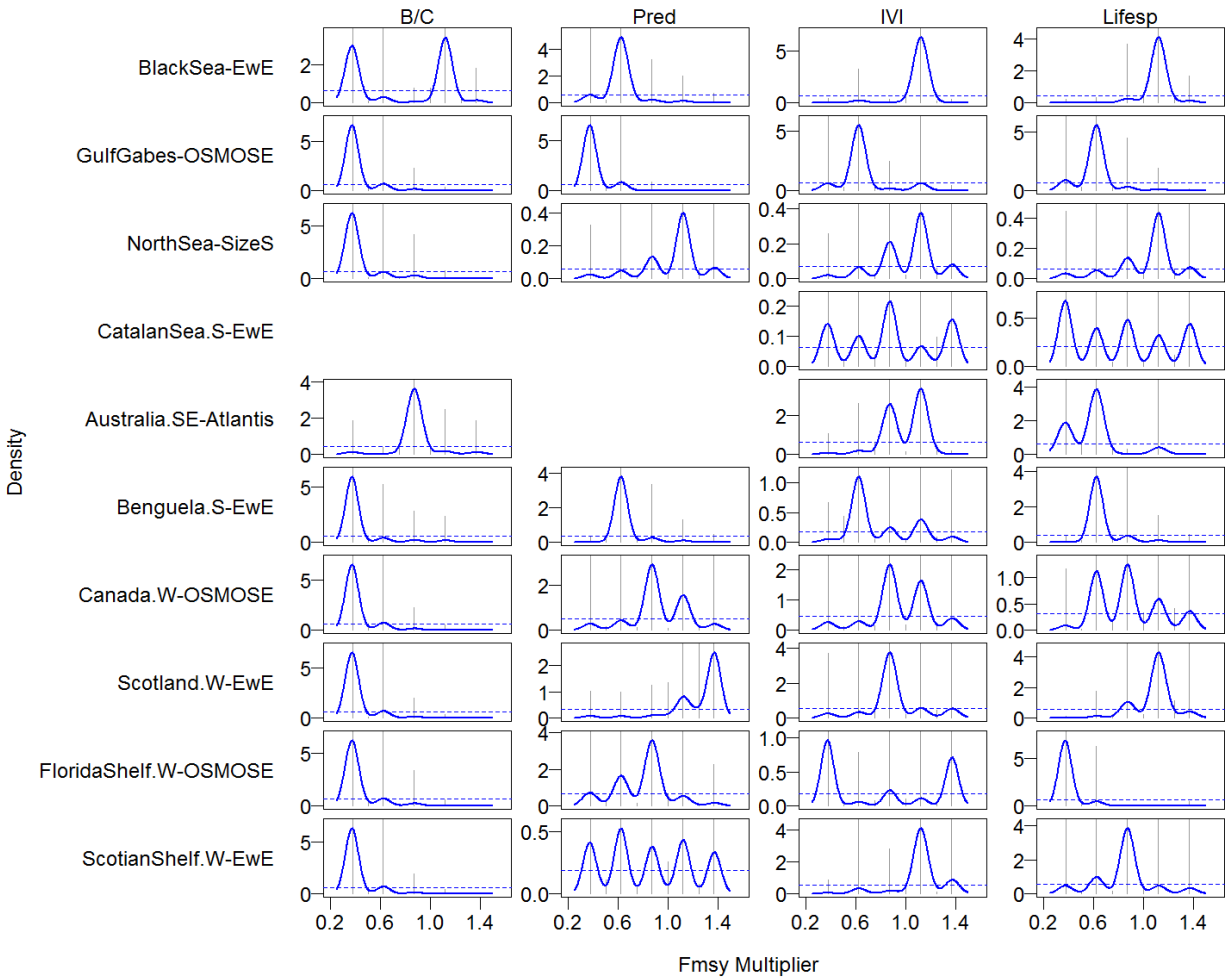

Fig. A5 Threshold shifts in the values of four indicators indicators (B/C: biomass to fisheries catch ratio, Pred: proportion of predatory fish, IVI: mean intrinsic vulnerability, and Lifesp: mean life span) along the gradient of fishing pressure under random change in primary productivity of standard deviation = 0.3. The dashed line indicates where the ratio of the density of split importance to the density of observed fishing pressure is 1; peaks above the dashed line suggest threshold values for the fishing pressure. Missing plots indicate failed convergence of the gradient forest model.

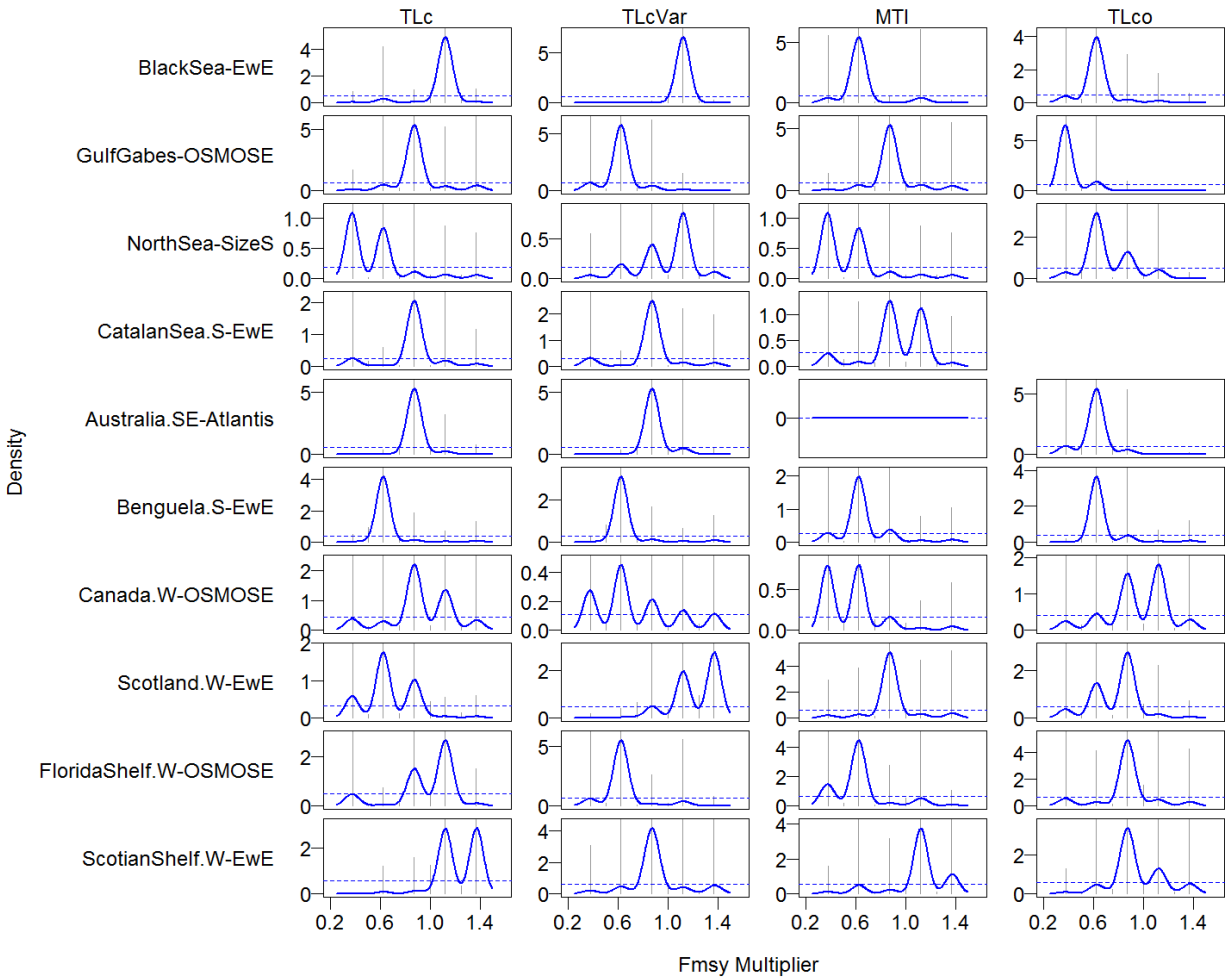

Fig. A6 Threshold shifts in the values of four trophic level (TL) based indicators (TLc: mean TL of catch, TLcVar: mean TL of catch with variable TL, MTI: marine trophic index, and TLco: mean TL of fish community surveyed) along the gradient of fishing pressure under random change in primary productivity of standard deviation = 0.3. The dashed line indicates where the ratio of the density of split importance to the density of observed fishing pressure is 1; peaks above the dashed line suggest threshold values for the fishing pressure. Missing plots indicate failed convergence of the gradient forest model.

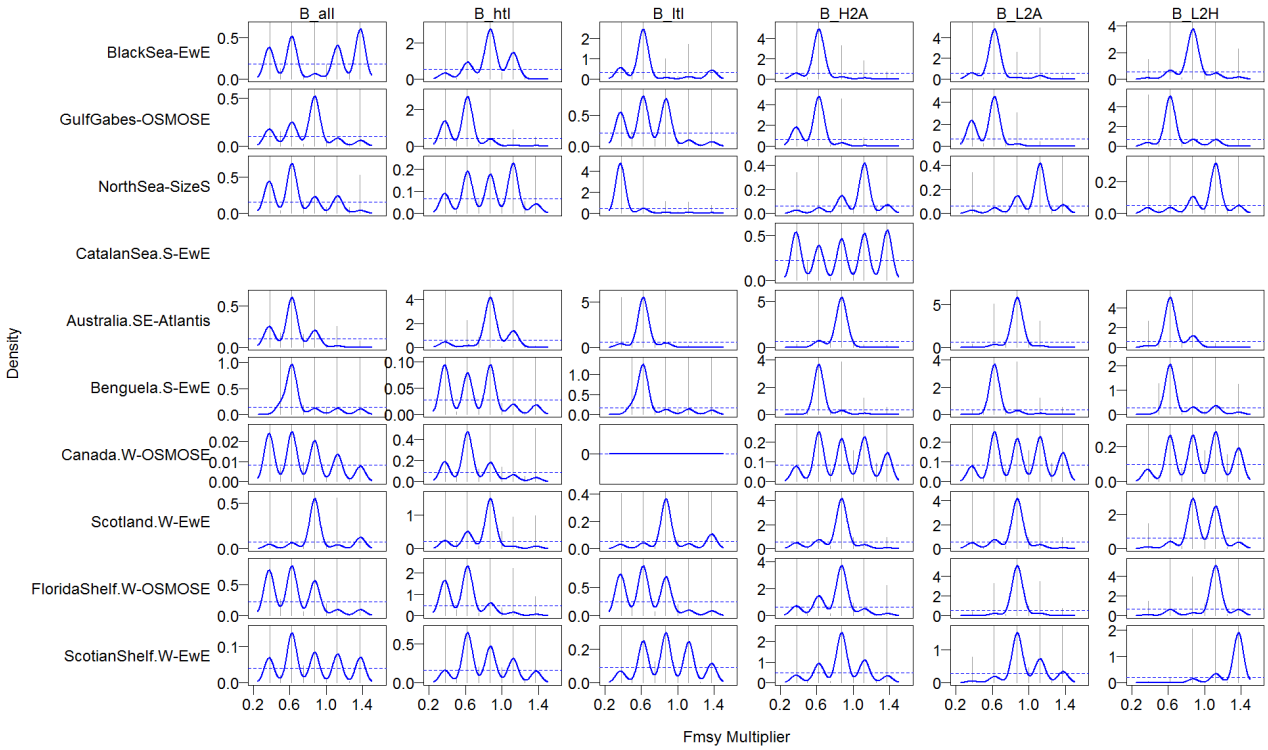

Fig. A7 Threshold shifts in the values of six biomass-based indicators (B_all: biomass of all species, B_htl: biomass of high-trophic-level species, B_all: biomass of low-trophic-level species, B_H2A: the ratio of B_htl to B_all, B_L2A: the ratio of B_ltl to B_all, and B_L2H: the ratio of B_ltl to B_htl) along the gradient of fishing pressure under random change in primary productivity of standard deviation = 0.3. The dashed line indicates where the ratio of the density of split importance to the density of observed fishing pressure is 1; peaks above the dashed line suggest threshold values for the fishing pressure. Missing plots indicate failed convergence of the gradient forest model.