Refinement of an Ecopath with Ecosim (EwE) model of the Clyde Sea for use within the Clyde Marine Region digital Maritime Spatial Planning (MSP) Challenge Game

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This report details the intensive modelling work undertaken to refine an existing 'Ecopath with Ecosim' (EwE) model (created for the Clyde at SAMS) for use within the development of the Clyde Marine Region version of the digital MSP Challenge game. This report follows the EwE methodology for best ecological practice (Heymans et al., 2016, Link, 2010) whilst also using (and developing) the EwE model guidelines for MSP gameplay (Steenbeek et al., In Prep).

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Ecopath

Original Clyde Sea model

The Clyde Sea Ecopath model (Heywood, 2009, not published) contains 37 functional groups ranging from detritus and plankton to marine mammals and seabirds, including important commercial species such as cod (*Gadus morhua*), whiting (*Merlangius merlangus*) and *Nephrops norvegicus*. The total area covered by the Clyde Sea model is 3631.7 km-2, or 1.5 % of ICES are VIa. This excludes the River Clyde's inner estuary. The Ecopath model was constructed to represent the Clyde Sea ecosystem in 1985, as this was the earliest year that accurate regional fisheries statistics were available. Data for the Clyde Sea model was principally sourced from Haggan and Pitcher's 2005 model of the West Coast of Scotland (WCofS). The basic estimates for the balanced Clyde Sea Ecopath model can be found in Table 1.

Table 1. *Basic estimates for the 1985 Ecopath model of the Clyde Sea, including trophic level (TL), biomass (B), production/biomass (P/B), consumption/ biomass (P/Q), ecotrophic efficiency (EE), production/consumption (P/Q) and biomass accumulation (BA). Parameters estimated by the model are in blue.*

	Functional group	TL	B ($t.km^{-2}$)	P/B ($year^{-1}$)	Q/B ($year^{-1}$)	EE	P/Q	BA ($t.km^{-2}.year^{-1}$)	BA ($year^{-1}$)
1	Seals	4.808	0.185	0.070	12.000	0.883	0.006		
2	Cetaceans	4.399	0.027	0.090	6.775	0.008	0.013		
3	Seabirds	4.039	0.005	0.800	53.500	0.837	0.015		
4	Halibut/turbot/brill	4.138	0.269	0.550	1.800	0.441	0.306		
5	Whiting	4.119	0.645	1.450	5.460	0.990	0.266	-0.953	-1.479
6	Other demersals	3.894	3.503	0.770	2.567	0.950	0.300		
7	Sharks	4.119	0.682	0.600	3.000	0.648	0.200		
8	Rays/Skates	3.854	1.400	0.480	1.450	0.724	0.331		
9	Cod	3.729	0.432	1.200	3.797	0.950	0.316	-0.197	-0.457
10	Saithe	3.963	0.795	0.870	4.023	0.003	0.216	-0.282	-0.355
11	Other pelagics	3.795	4.326	0.869	2.895	0.221	0.300		
12	Crabs/lobsters	3.672	1.405	0.780	5.200	0.991	0.150		
13	Gurnards	3.691	0.150	1.400	4.610	0.638	0.304		
14	Haddock	3.697	0.300	1.000	4.000	0.950	0.250	-0.195	-0.650
15	Inshore fish	3.585	0.207	5.000	16.667	0.711	0.300		
16	Salmo	3.570	0.039	0.800	3.570	0.676	0.224		
17	Mackerel	3.366	0.835	1.021	3.950	0.470	0.258		
18	Trachurus	3.237	1.873	0.700	2.900	0.703	0.241		
19	Plaice	3.454	1.637	0.975	3.420	0.689	0.285		
20	Sole	3.377	0.456	0.800	2.700	0.910	0.296		
21	Nephrops	3.316	4.493	0.730	4.867	0.916	0.150		
22	Norway pout	3.231	0.541	2.000	7.000	0.950	0.286		
23	Cephalopods	3.165	0.386	3.000	10.000	0.751	0.300		
24	Sandeel	3.228	0.876	3.000	10.250	0.602	0.293		
25	Sprat	3.152	1.484	1.900	8.500	0.950	0.224		
26	Herring	3.151	0.843	1.800	7.000	0.950	0.257	-2.026	-2.405
27	Echinoderms	3.001	3.945	4.000	16.000	0.924	0.250		
28	Other benthic inverts	2.666	7.305	6.000	24.000	0.950	0.250		
29	Prawns/shrimps	2.473	16.312	3.000	12.000	0.821	0.250		
30	Euphausiids	2.258	2.317	9.000	36.000	0.715	0.250		
31	Large zooplankton	2.055	6.288	10.000	35.000	0.692	0.286		
32	Polychaetes	2.037	10.000	5.000	16.667	0.430	0.300		
33	Small zooplankton	2.031	7.809	18.000	72.000	0.800	0.250		
34	Epifauna	2.000	10.584	20.000	80.000	0.384	0.250		
35	Infauna	2.000	1.561	20.000	80.000	0.734	0.250		
36	Phytoplankton	1.000	80.000	70.000		0.182			
37	Detritus	1.000	100.000			0.211			

Condensing functional groups to create smaller models

For the purpose of this project, the number of functional groups in the model needed to be kept as low as possible to ensure fast Ecospace run times. The model was reduced from 37 to 24 functional groups using Ecopath version 5.1. Key species such as cod and *Nephrops* were left as single functional groups whilst species with less relevance towards the MSP objectives were aggregated into the appropriate ecological groups (Table 2). To ensure the resulting ecological parameters were realistic we also aggregated the functional groups in the most recent version of the West Coast of Scotland (WCofS) EwE model (Serpetti et al., submitted). The WCofS aggregated groups were designed to mimic those of the aggregated Clyde model (Table 3). The condensed Clyde model produced unbalanced Ecopath estimates for rays and skates, cod, haddock (*Melanogrammus aeglefinus*) and whiting. The unbalanced parameters can be seen in Table 4, with the models diet in Table 5. The condensed WCofS model was balanced after the initial run. The parameters for the WCofS can be can be seen in Table 6 and the accompanying diet can be found in Table 7.

Table 2. Functional group structure for the condensed Clyde Sea Ecopath model

Functional group	Included groups
1 Seals	-
2 Cetaceans	-
3 Birds	-
4 Sharks	-
5 Rays and skates	-
6 Cod	-
7 Haddock	-
8 Saithe	-
9 Whiting	-
10 Other demersals	Gurnards; Inshore fish; Norway pout
11 Flatfish	Halibut; Turbot; Brill; Plaice; Sole
12 Mackerel	-
13 Herring	-
14 Sandeels	-
15 Other pelagic	Horse mackerel; Sprat
16 Crabs and lobsters	-
17 Nephrops	-
18 Prawns and shrimp	-
19 Cephalopods	-
20 Other invertebrates	Echinoderms; Polychaetes; Epifauna; Infauna
21 Large zooplankton	Euphausiids
22 Small zooplankton	-
23 Phytoplankton	-
24 Detritus	-

Table 3. Functional group structure for the condensed West Coast of Scotland Ecopath model.

Functional group	Included groups
1 Seals	Grey seals; Harbour seals
2 Cetaceans	-
3 Birds	-
4 Sharks	-
5 Rays and skates	-
6 Cod	Cod mature; Cod imature
7 Haddock	Haddock mature; Haddock imature
8 Saithe	-
9 Whiting	Whiting mature; Whiting imature
10 Other demersals	Gurnards; Monkfish; Large demersals; Other small fish; Norway pout; Poor cod
11 Flatfish	-
12 Mackerel	-
13 Herring	-
14 Sandeels	-
15 Other pelagic	Horse mackerel; Blue whiting; Sprat
16 Crabs and lobsters	-
17 Nephrops	-
18 Prawns and shrimp	-
19 Cephalopods	-
20 Other invertebrates	Infauna; Epifauna; Scallops
21 Large zooplankton	-
22 Small zooplankton	-
23 Phytoplankton	-
24 Algae	-
25 Detritus	-

***Table 4.** Basic estimates for the condensed 1985 Ecopath model of the Clyde Sea, including trophic level (TL), biomass (B), production/biomass (P/B), consumption/ biomass (P/Q), ecotrophic efficiency (EE) and production/consumption (P/Q). Parameters estimated by the model are in blue, EE values which are unbalanced (>1) are highlighted red and P/Q estimates which exceed ecological limits are underlined.*

Functional group	TL	B ($t.km^{-2}$)	P/B ($year^{-1}$)	Q/B ($year^{-1}$)	EE	P/Q
Seals	4.711	0.185	0.070	12.000	0.884	0.006
Cetaceans	4.066	0.027	0.090	6.775	0.008	0.013
Birds	3.935	0.005	0.800	53.500	0.835	0.015
Sharks	4.060	0.682	0.600	3.000	0.648	0.200
Rays and skates	3.732	1.400	0.480	1.450	1.350	0.331
Cod	3.630	0.432	1.200	3.797	1.329	0.316
Haddock	3.484	0.300	1.000	4.000	1.588	0.250
Saithe	4.012	0.795	0.870	4.023	0.412	0.216
Whiting	4.069	0.645	1.450	5.460	2.035	0.266
Other demersals	3.668	6.938	0.816	2.726	0.950	0.299
Flatfish	3.248	2.362	0.893	3.097	0.778	0.288
Mackerel	3.314	0.835	1.021	3.950	0.775	0.258
Herring	3.160	2.145	1.800	7.000	0.950	0.257
Sandeels	3.256	0.876	3.000	10.250	0.738	0.293
Other pelagic	3.277	9.806	1.216	4.958	0.410	0.245
Crabs and lobsters	3.379	1.540	0.780	5.200	0.950	0.150
Nephrops	3.106	4.493	0.730	4.867	0.948	0.150
Prawns and shrimp	2.467	16.312	3.000	12.000	0.941	0.250
Cephalopods	3.198	0.386	3.000	10.000	0.749	0.300
Other invertebrates	2.133	33.397	10.556	41.224	0.521	0.256
Large zooplankton	2.112	8.605	9.731	35.269	0.932	0.276
Small zooplankton	2.031	7.809	18.000	72.000	0.796	0.250
Phytoplankton	1.000	80.000	70.000	0.000	0.182	
Detritus	1.000	100.000			0.000	

***Table 5.** Diet matrix for the condensed Ecopath model of the Clyde sea*

	Seals	Cetaceans	Birds	Sharks	Rays and skates	Cod	Haddock	Saithe	Whiting	Other demersals	Flatfish
Seals	0.001			0.005							
Cetaceans				0.000							
Birds	0.001	0.001		0.001							
Sharks		0.000		0.041							0.000
Rays and skates	0.000			0.001						0.046	
Cod	0.010	0.002	0.003	0.023		0.010		0.052	0.009	0.001	0.001
Haddock	0.010	0.000	0.000	0.002		0.020	0.000	0.037	0.014	0.000	0.002
Saithe		0.001		0.001		0.016			0.007	0.000	
Whiting	0.386	0.001	0.004	0.029					0.010	0.008	0.009
Other demersals	0.352	0.069	0.101	0.028	0.015	0.017	0.052	0.200	0.143	0.095	0.002
Flatfish	0.003		0.035	0.001	0.041	0.039		0.029	0.001	0.013	
Mackerel	0.014	0.001		0.017		0.006				0.028	
Herring	0.140	0.001	0.296	0.316	0.130	0.093	0.001	0.150	0.100	0.028	
Sandeels	0.024	0.076	0.100	0.020	0.050	0.044	0.030	0.030	0.050	0.046	
Other pelagic	0.051	0.642	0.100	0.106	0.050	0.011	0.098	0.162	0.393	0.053	
Crabs and lobsters	0.001		0.050	0.009	0.024					0.040	0.000
Nephrops			0.000		0.130	0.014				0.009	0.001
Prawns and shrimp		0.002	0.004	0.100	0.380	0.474	0.370	0.115	0.128	0.161	0.204
Cephalopods	0.007	0.005		0.150		0.018		0.005			0.021
Other invertebrates		0.000	0.306	0.109	0.180	0.239	0.448		0.125	0.387	0.748
Large zooplankton		0.129		0.040				0.220	0.020	0.085	0.012
Small zooplankton		0.070									

	Mackerel	Herring	Sandeels	Other pelagic	Crabs and lobsters	Nephrops	Prawns and shrimp	Cephalopods	Other invertebrates	Large zooplankton	Small zooplankton
Cod	0.005										
Haddock	0.007			0.002				0.004			
Whiting	0.011										
Other demersals	0.017			0.004	0.105			0.006			
Flatfish			0.001	0.019				0.016			
Herring	0.020			0.007				0.019			
Sandeels	0.010	0.000		0.007				0.019			
Other pelagic	0.040	0.000		0.020				0.025			
Crabs and lobsters					0.005			0.002			
Nephrops				0.025	0.010			0.002			
Prawns and shrimp	0.185	0.154	0.403	0.180	0.207		0.110				
Cephalopods				0.007							
Other invertebrates	0.005		0.001	0.131	0.673	0.339	0.014	0.024	0.106		
Large zooplankton	0.600	0.838	0.594	0.565		0.499	0.065	0.604		0.007	
Small zooplankton	0.100		0.001	0.033		0.161	0.211	0.279	0.012	0.101	0.030
Phytoplankton		0.007					0.200		0.216	0.773	0.800
Detritus							0.400		0.666	0.119	0.170

Table 6. Basic estimates for the condensed 1985 Ecopath model of the West Coast of Scotland, including trophic level (TL), biomass (B), production/biomass (P/B), consumption/ biomass (P/Q), ecotrophic efficiency (EE) and production/consumption (P/Q). Parameters estimated by the model are in blue. Algae, a functional group not included in the Clyde Sea model, is highlighted in grey.

	Functional group	TL	B (t.km^{-2})	P/B (year^{-1})	Q/B (year^{-1})	EE	P/Q
1	Seals	4.339	0.047	0.111	11.090	0.000	0.010
2	Cetaceans	4.129	0.126	0.020	14.000	0.000	0.001
3	Seabirds	4.156	0.025	0.400	83.051	0.000	0.005
4	Sharks	4.064	0.242	0.682	3.410	0.950	0.200
5	Rays and skates	3.805	0.119	0.449	2.243	0.950	0.200
6	Cod	3.436	0.560	1.644	6.112	0.759	0.269
7	Haddock	3.174	0.979	1.371	7.542	0.671	0.182
8	Saithe	4.046	0.505	0.937	4.686	0.616	0.200
9	Whiting	3.421	0.785	1.423	6.776	0.808	0.210
10	Other demersals	3.458	3.494	1.188	4.282	0.950	0.277
11	Flatfish	3.356	0.809	1.130	3.768	0.950	0.300
12	Mackerel	3.354	4.319	0.626	4.400	0.663	0.142
13	Herring	3.156	5.943	1.500	10.100	0.721	0.149
14	Sandeels	3.183	1.388	1.826	6.085	0.950	0.300
15	Other pelagic	3.380	9.841	1.344	5.095	0.848	0.264
16	Crabs and lobsters	2.796	3.336	0.425	4.895	0.947	0.087
17	Nephrops	3.318	1.000	0.730	4.876	0.518	0.150
18	Prawns and shrimp	2.661	14.419	0.871	5.806	0.950	0.150
19	Cephalopods	3.248	1.234	1.981	15.000	0.950	0.132
20	Other invertebrates	2.164	16.080	8.042	39.845	0.952	0.202
21	Large zooplankton	2.158	15.306	10.000	35.000	0.950	0.286
22	Small zooplankton	2.031	8.220	18.000	72.000	0.950	0.250
23	Phytoplankton	1.000	17.368	70.000	0.000	0.950	
24	Algae	1.000	5.995	5.000	0.000	0.950	
25	Detritus	1.000	100.000			0.864	

Table 7. Diet matrix for the condensed Ecopath model of the West Coast of Scotland.

	Seals	Cetaceans	Seabirds	Sharks	Rays and skates	Cod	Haddock	Saithe	Whiting	Other demersals	Flatfish
Sharks		0.000		0.042							
Rays and skates				0.010	0.001	0.000				0.000	
Cod	0.087	0.002	0.027	0.021		0.033		0.052	0.006	0.002	0.002
Haddock	0.048	0.000	0.006	0.007	0.009	0.028	0.003	0.039	0.003	0.001	0.001
Saithe	0.047	0.001	0.007	0.001					0.002	0.001	0.001
Whiting	0.071	0.001	0.003	0.030	0.033	0.044		0.036	0.016	0.007	0.001
Other demersals	0.170	0.079	0.052	0.048	0.016	0.005	0.020	0.201	0.007	0.046	0.029
Flatfish	0.077			0.010	0.041	0.012		0.029	0.000	0.008	0.004
Mackerel	0.004	0.001	0.030	0.017		0.002			0.042	0.030	0.005
Herring	0.059	0.001	0.356	0.301	0.130	0.028	0.000	0.147	0.114	0.017	
Sandeels	0.346	0.077	0.086	0.021	0.050	0.041	0.011	0.030	0.030	0.005	0.020
Other pelagic	0.090	0.643	0.307	0.108	0.050	0.039	0.037	0.163	0.089	0.068	0.038
Crabs and lobsters				0.002	0.007	0.002			0.001	0.000	0.001
Nephrops					0.130	0.004				0.001	0.021
Prawns and shrimp		0.002	0.035	0.110	0.249	0.119	0.171	0.115	0.035	0.131	0.106
Cephalopods	0.002	0.004		0.120		0.006		0.005	0.010	0.007	0.007
Other invertebrates		0.000	0.071	0.111	0.284	0.183	0.226		0.121	0.139	0.562
Large zooplankton		0.119	0.020	0.041		0.246	0.313	0.183	0.305	0.537	0.100
Small zooplankton		0.070				0.174	0.094		0.135	0.000	0.102
Phytoplankton						0.035	0.125		0.084		

	Mackerel	Herring	Sandeels	Other pelagic	Crabs and lobsters	Nephrops	Prawns and shrimp	Cephalopods	Other invertebrates	Large zooplankton	Small zooplankton
Cod	0.005										
Haddock	0.007			0.004				0.004			
Whiting	0.007			0.002							
Other demersals	0.017			0.023			0.001	0.012			
Flatfish				0.001	0.011			0.015			
Herring	0.100			0.026				0.027			
Sandeels	0.010	0.000		0.011				0.019			
Other pelagic	0.040	0.000		0.087				0.030			
Crabs and lobsters					0.018	0.200					
Nephrops				0.000			0.001	0.002			
Prawns and shrimp	0.010	0.010	0.050	0.018	0.233	0.100	0.010	0.002			
Cephalopods				0.040							
Other invertebrates	0.005		0.001	0.169	0.301	0.339	0.373	0.024	0.108		
Large zooplankton	0.699	0.982	0.948	0.517		0.199	0.084	0.592		0.012	
Small zooplankton	0.100		0.001	0.102	0.000	0.161	0.105	0.273	0.037	0.140	0.030
Phytoplankton		0.007					0.100		0.454	0.710	0.800
Algae					0.292				0.037		
Detritus					0.145		0.326		0.364	0.138	0.170

Collapsing fishing fleets to match MSP interests

The original model of the Clyde Sea included 8 fishing fleets (Table 8). The fleets of interest for MSP gameplay purposes (for which pressure data existed) include ‘Demersal trawl’, ‘Scallop fleet’, ‘Nephrops fleet’, ‘Pots and creel’ and ‘Seine’. To match the interests of the MSP gameplay, ‘Hand collecting’ and ‘Dredge’ fleets (which both only land ‘Other invertebrates’ (likely scallops)) were collapsed into a single ‘Scallop fleet’ fishery. Landings from the ‘Pelagic trawl’ fleet were added to the ‘Seine’ fleet. The ‘Pelagic trawl’ fleet was then removed. The catches from ‘Line fishing’ were minimal (no impact on total landings) and pressure data does not exist to drive the fleet temporally or spatially. The fleet was therefore removed, leaving only the 5 fleets of interest remaining (Table 9).

Table 8. *Fishing fleets and landings (t.km^{-2}) from the original Ecopath model of the Clyde Sea.*

Functional group	Fishing fleet								Total
	Demersal trawl	Dredge	Hand collecting	Line fishing	Nephrops fleet	Pelagic trawl	Pots and creels	Seine	
1 Seals	-	-	-	-	-	-	-	-	-
2 Cetaceans	-	-	-	-	-	-	-	-	-
3 Birds	-	-	-	-	-	-	-	-	-
4 Sharks	0.0538	-	-	-	0.0368	0.0166	-	0.0666	0.1784
5 Rays and skates	0.0073	-	-	0.00002	0.0047	-	-	0.0086	0.0206
6 Cod	0.2090	-	-	-	0.0772	-	-	0.0527	0.3389
7 Haddock	0.0118	-	-	-	0.0051	-	-	0.0176	0.0345
8 Saithe	0.1380	-	-	-	0.0404	-	-	0.0154	0.1938
9 Whiting	0.1790	-	-	-	0.1000	-	-	0.1830	0.4620
10 Other demersals	0.0295	-	-	0.00004	0.0448	-	-	0.0418	0.1161
11 Flatfish	0.0215	-	-	-	0.0201	-	-	0.0219	0.0635
12 Mackerel	0.0002	-	-	-	0.0023	0.0308	-	0.0003	0.0336
13 Herring	0.0021	-	-	-	0.0081	0.3410	-	0.0001	0.3512
14 Sandeels	-	-	-	-	-	-	-	-	-
15 Other pelagic	0.0096	-	-	-	0.0004	0.0256	-	0.0011	0.0367
16 Crabs and lobsters	-	-	-	-	-	-	0.0095	-	0.0095
17 Nephrops	0.0440	-	-	-	0.5850	-	0.0003	0.0000	0.6294
18 Prawns and shrimp	-	-	-	-	-	-	-	-	-
19 Cephalopods	0.0003	-	-	-	0.0012	-	-	0.0029	0.0045
20 Other invertebrates	0.0240	0.0305	0.0889	-	0.0004	-	-	-	0.1438
21 Large zooplankton	-	-	-	-	-	-	-	-	-
22 Small zooplankton	-	-	-	-	-	-	-	-	-
23 Phytoplankton	-	-	-	-	-	-	-	-	-
24 Detritus	-	-	-	-	-	-	-	-	-
Sum	0.7301	0.0305	0.0889	0.0046	0.9266	0.4140	0.0099	0.4120	2.6166

Functional group	Fishing Fleet					Total
	Demersal trawl	Scallop fleet	Nephrops fleet	Pots and creels	Seine	
1 Seals	-	-	-	-	-	-
2 Cetaceans	-	-	-	-	-	-
3 Birds	-	-	-	-	-	-
4 Sharks	0.0538	-	0.0368	-	0.0832	0.1738
5 Rays and skates	0.0073	-	0.0047	-	0.0086	0.0206
6 Cod	0.2090	-	0.0772	-	0.0527	0.3389
7 Haddock	0.0118	-	0.0051	-	0.0176	0.0345
8 Saithe	0.1380	-	0.0404	-	0.0154	0.1938
9 Whiting	0.1790	-	0.1000	-	0.1830	0.4620
10 Other demersals	0.0295	-	0.0448	-	0.0418	0.1161
11 Flatfish	0.0215	-	0.0201	-	0.0219	0.0635
12 Mackerel	0.0002	-	0.0023	-	0.0311	0.0336
13 Herring	0.0021	-	0.0081	-	0.3411	0.3512
14 Sandeels	-	-	-	-	-	-
15 Other pelagic	0.0096	-	0.0004	-	0.0267	0.0367
16 Crabs and lobsters	-	-	-	0.0095	-	0.0095
17 Nephrops	0.0440	-	0.5850	0.0003	0.0000	0.6294
18 Prawns and shrimp	-	-	-	-	-	-
19 Cephalopods	0.0003	-	0.0012	-	0.0029	0.0045
20 Other invertebrates	0.0240	0.1194	0.0004	-	-	0.1438
21 Large zooplankton	-	-	-	-	-	-
22 Small zooplankton	-	-	-	-	-	-
23 Phytoplankton	-	-	-	-	-	-
24 Detritus	-	-	-	-	-	-
Sum	0.7301	0.1194	0.9266	0.0099	0.8260	2.6120

Table 9. *Fishing fleets and landings (t.km^{-2}) for the updated Ecopath model of the Clyde Sea. Fleets have been collapsed into 5 categories to match MSP gameplay objectives.*

PREBAL

Trophic level:

The calculated Ecopath trophic levels for Clyde and WCofS functional groups are generally very similar (Figure 1), spanning approximately 4.5 trophic levels. Seals, whiting, haddock and crabs and lobsters have slightly higher trophic levels in the Clyde model, whilst seabirds and nephrops have slightly lower trophic levels in the Clyde model.

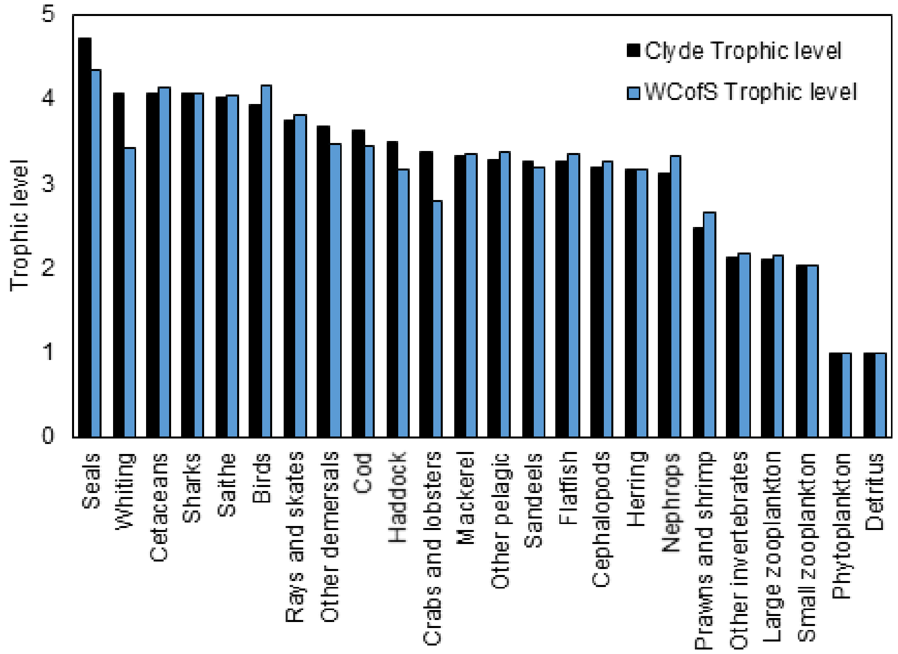


Figure 1. *Comparison of the trophic levels of functional groups in the condensed Ecopath models of the Clyde Sea and West Coast of Scotland.*

Biomass:

Biomass, spanning 6 orders of magnitude, tends to decrease with increasing trophic levels in the Clyde model, with estimates closely resembling those in the WCofS model (Figure 2). Functional groups with estimates noticeably above the trend line include phytoplankton, other invertebrates and other demersals. Cetaceans, haddock, birds and cephalopods fall below the trend line.

Production/biomass (P/B):

P/B follows a decreasing trend with increasing trophic level in the Clyde model, with estimates resembling WCofS estimates (Figure 3). Cetaceans exhibit a noticeably larger P/B in the Clyde model than in the WCofS model. Estimates in the WCofS model are likely more reliable and will therefore be used to guide the balancing process of the Clyde model.

Consumption/biomass (Q/B):

Q/B follows a decreasing trend with increasing trophic level in the Clyde model (Figure 4). Q/B ratios for sharks, saithe, other demersals, cod, haddock and herring are below the line and may benefit from the use of WCofS Q/B ratios. Seabirds and cetacean's have low Q/B ratios compared to the WCofS estimates. Seabird Q/B is dramatically high, however this has been encountered in previous models (Bentley et al., 2017) and is likely resultant of the high energy demanding lifestyles of seabirds.

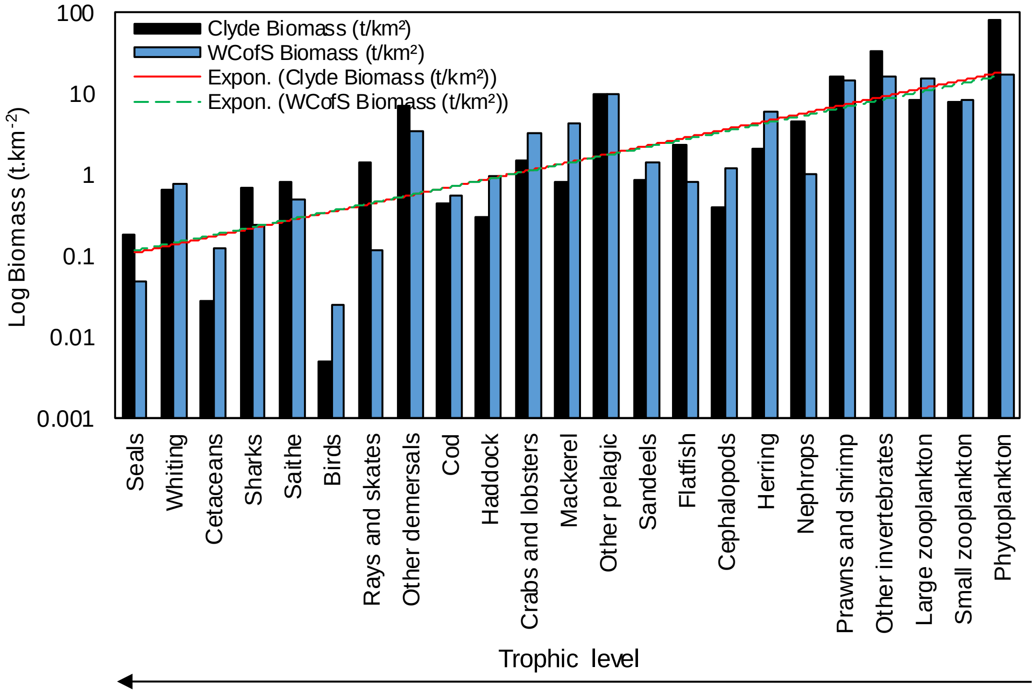


Figure 2. Comparison of the production/biomass ratios of the functional groups in the condensed Ecopath models of the Clyde Sea and West Coast of Scotland. Trophic level increases from right to left using Clyde Sea estimates.

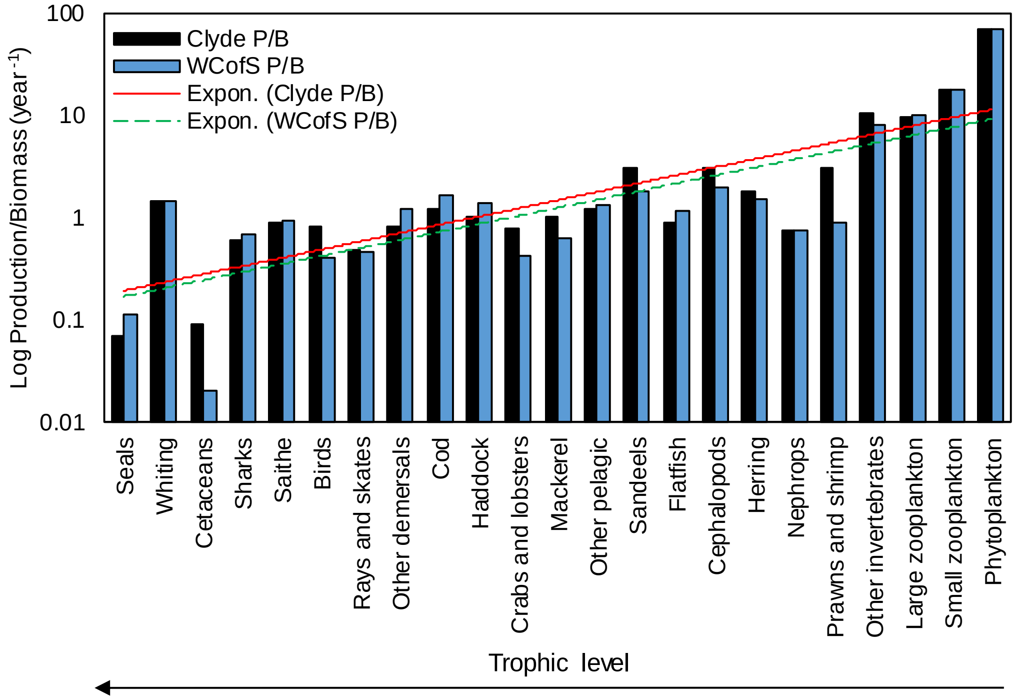


Figure 3. Comparison of the consumption/biomass ratios of the functional groups in the condensed Ecopath models of the Clyde Sea and West Coast of Scotland. Trophic level increases from right to left using Clyde Sea estimates.

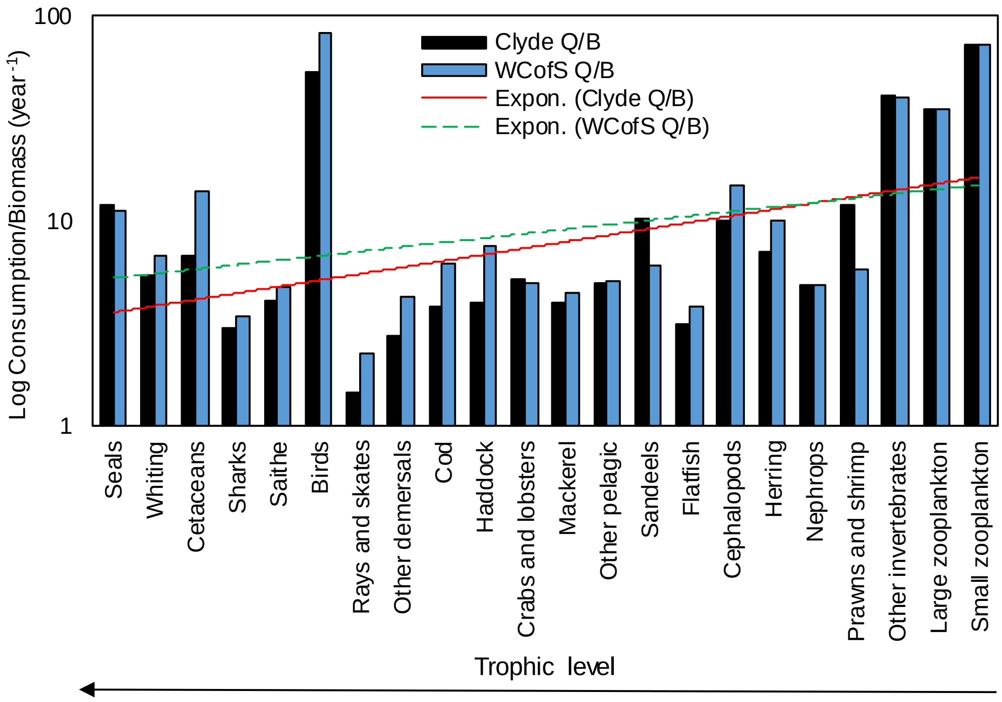


Figure 4. Comparison of the consumption/biomass ratios of the functional groups in the condensed Ecopath models of the Clyde Sea and West Coast of Scotland. Trophic level increases from right to left using Clyde Sea estimates.

Production/consumption (P/Q):

P/Q ratios indicate that groups cannot produce more than a fraction of what is eaten. Generally, they should fall between 0.1 and 0.3 for poikliotherms in order to achieve ecological coherence (Heymans et al., 2015). Homeotherms are exempt from this rule (Link, 2010). In the Clyde model, rays and skates and cod have high P/Q ratios (>0.3) whilst whiting, haddock, mackerel, herring, prawns and shrimps and other invertebrates show large discrepancies when compared to WCofS values (Figure 5).

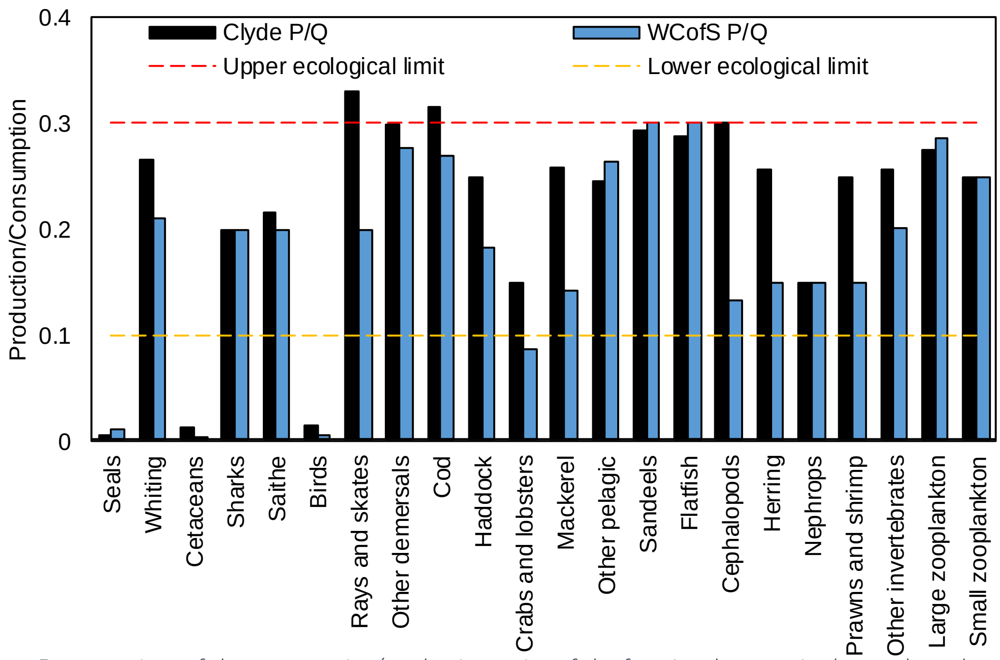


Figure 5. Comparison of the consumption/production ratios of the functional groups in the condensed Ecopath models of the Clyde Sea and West Coast of Scotland, including the lower (0.1) and upper (0.3) ecological limits.

Comparing the diets of the Clyde and WCofS model

14/22 of the consumer functional groups in the condensed Clyde Sea model show high correlation (>0.75) when compared to the diets of the same functional groups in the condensed WCofS model (Table 10). The full diets can be found in Figure 6.

Table 10. *Correlation between functional group diets in the condensed Clyde and West Coast of Scotland Ecopath models.*

Funtional group	Correlation
Small zooplankton	1.0000
Cephalopods	0.9998
Cetaceans	0.9997
Large zooplankton	0.9972
Sharks	0.9932
Saithe	0.9897
Herring	0.9851
Flatfish	0.9655
Mackerel	0.9514
Other pelagic	0.9349
Rays and skates	0.9137
Sandeels	0.8492
Other invertebrates	0.8221
Nephrops	0.7755
Birds	0.7057
Crabs and lobsters	0.6709
Prawns and shrimp	0.6352
Haddock	0.5726
Other demersals	0.4141
Cod	0.4011
Seals	0.3657
Whiting	0.2387

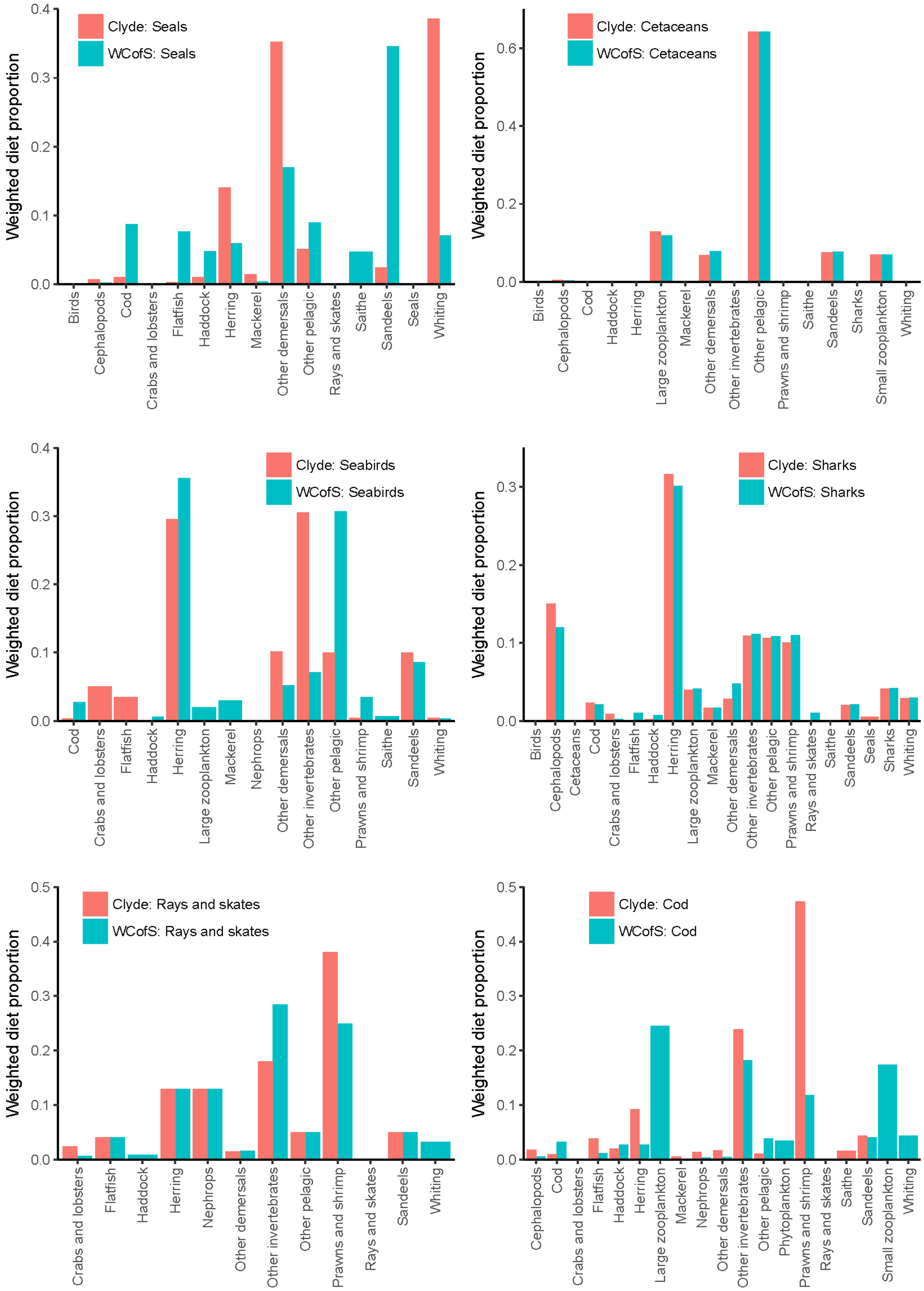


Figure 6. Comparisons of the diets of functional groups included in condensed Clyde sea and West Coast of Scotland Ecopath models.

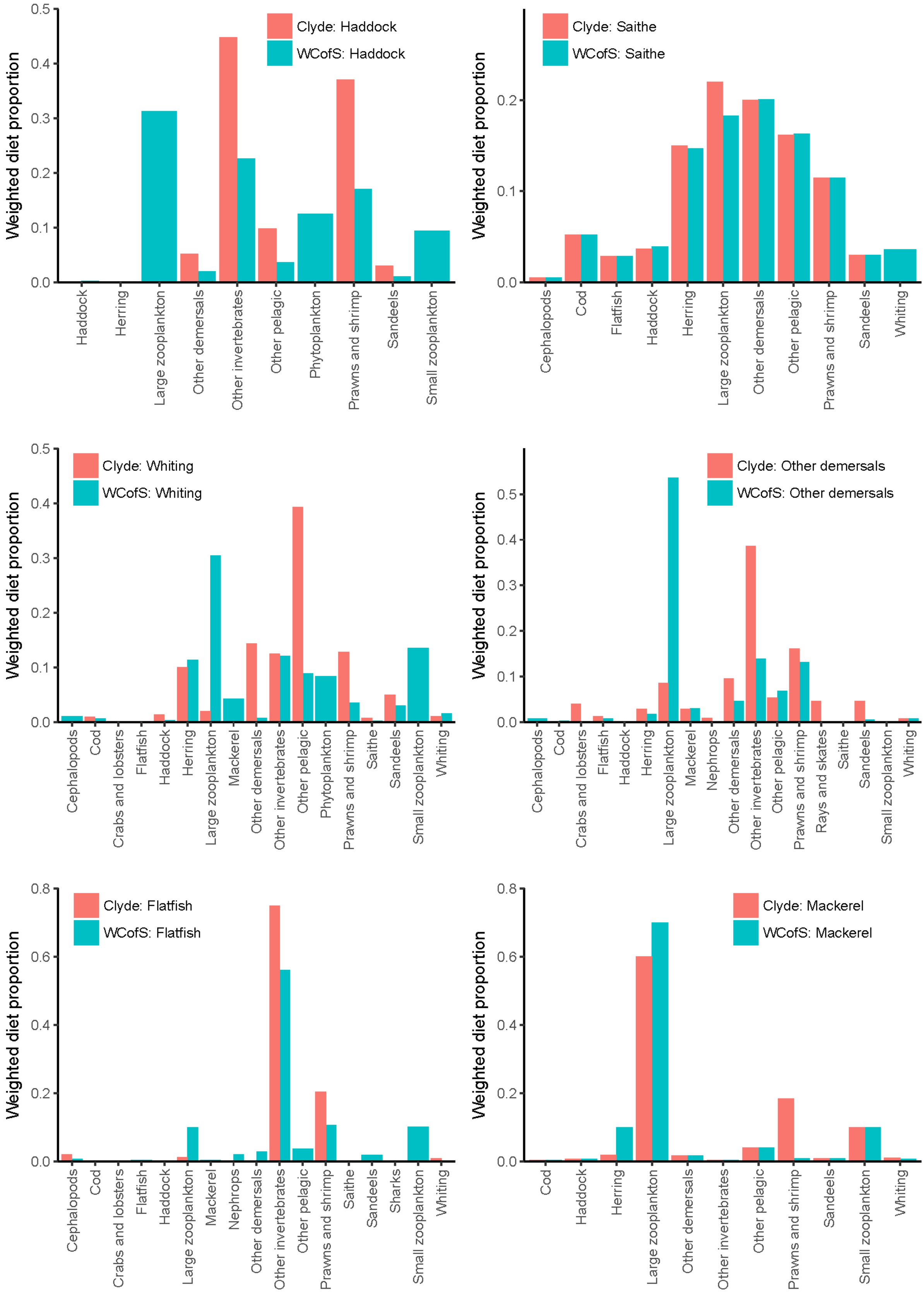


Figure 6. continued

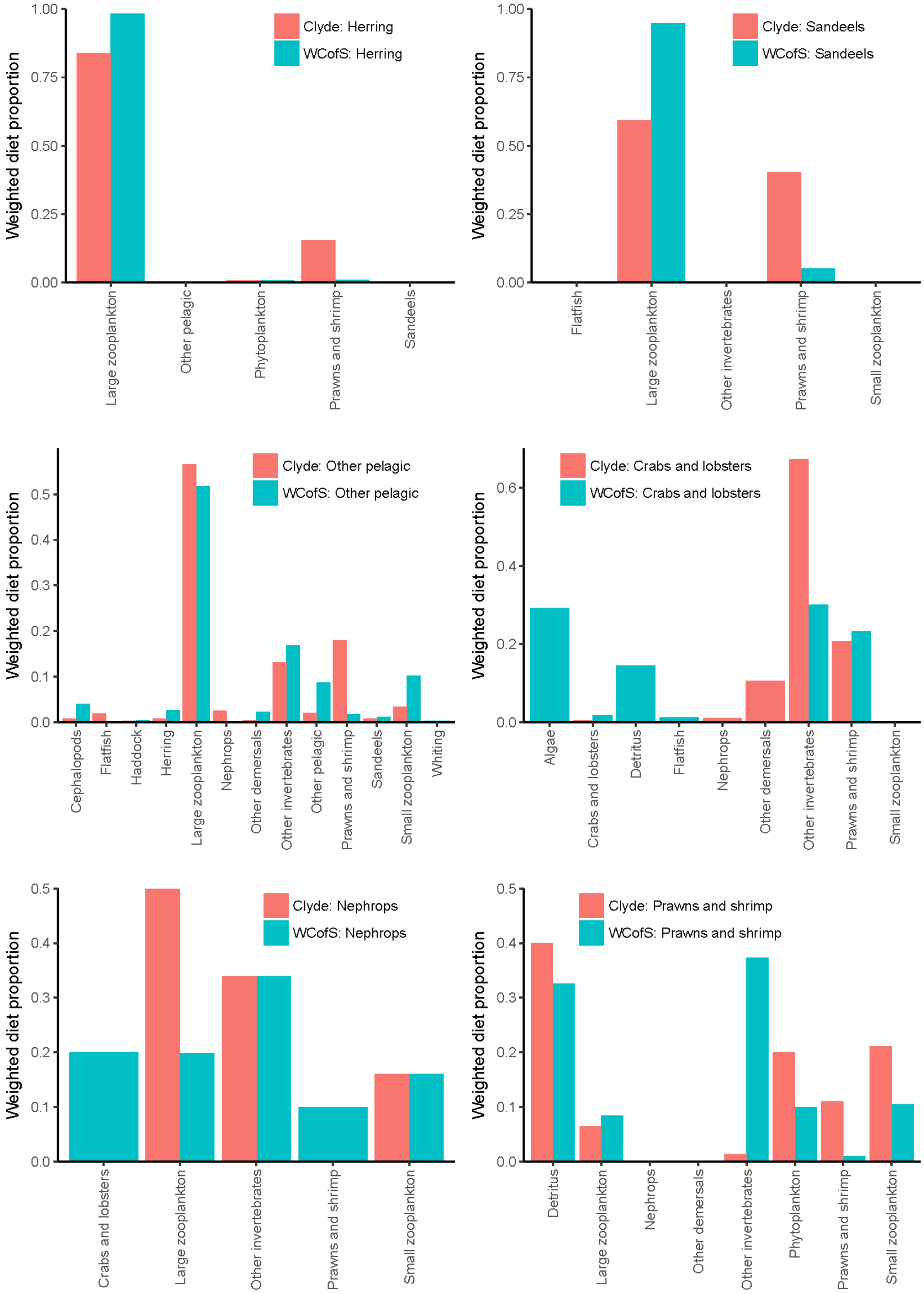


Figure 6. continued

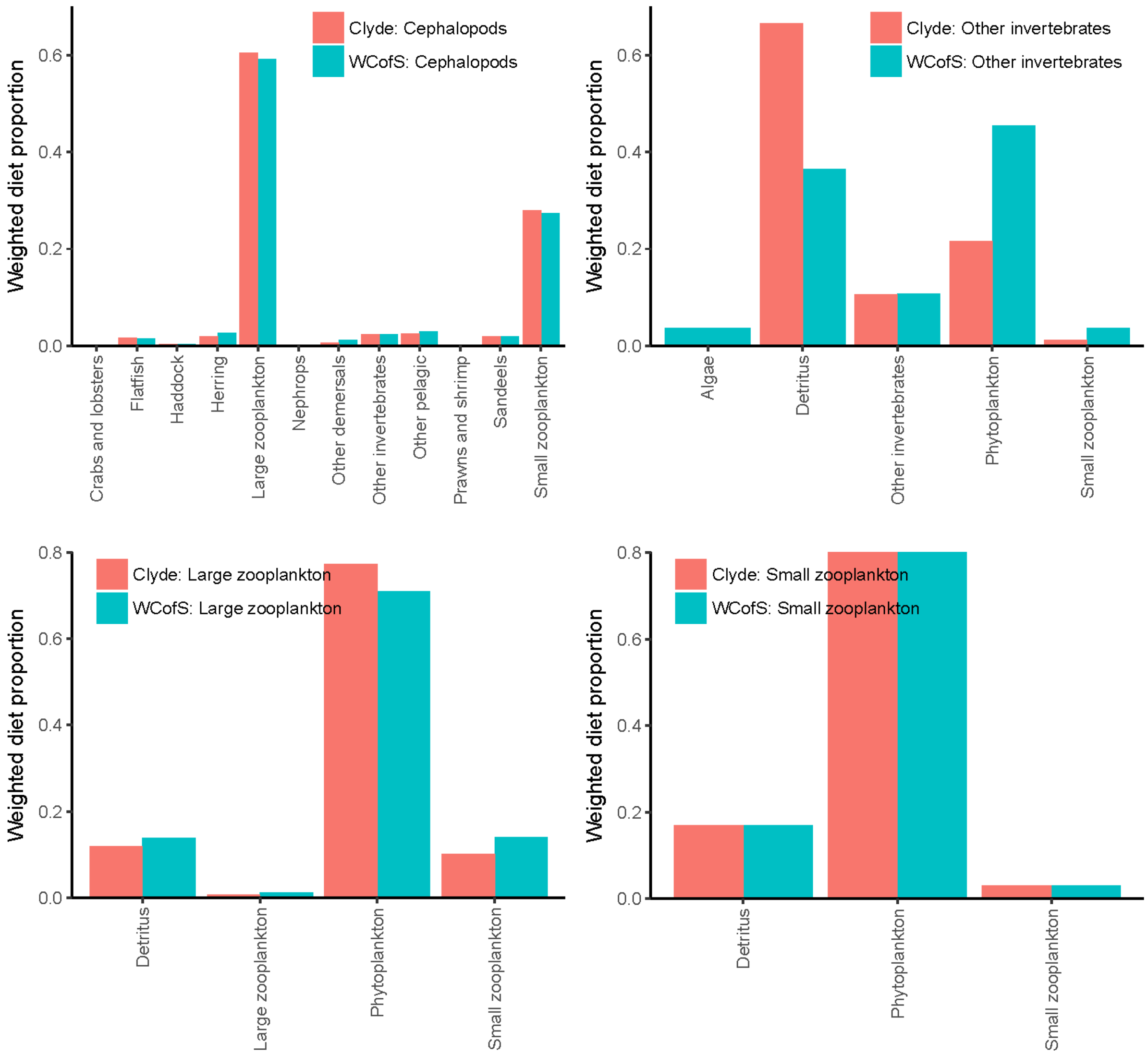


Figure 6. continued

Balancing the condensed Clyde Sea Model

Step 1: Highlight Issues

Issue 1: High EE estimates in the Clyde model

- Rays and Skates (1.350)
- Cod (1.329)
- Haddock (1.588)
- Whiting (2.035)

Issue 2: High P/Q (>0.3) in the Clyde Model

- Rays and Skates (0.331)
- Cod (0.316)
- Cephalopods (0.3)

Issue 3: Trophic level discrepancies between Clyde and WCofS:

- Seals: 4.711 in Clyde; 4.339 in WCofS (Diet correlation = 0.3657)

- Whiting: 4.069 in Clyde; 3.421 in WCofS (Diet correlation = 0.2387)
- Haddock: 3.484 in Clyde; 3.174 in WCofS (Diet correlation = 0.5726)
- Crabs and Lobsters: 3.379 in Clyde; 2.796 in WCofS (Diet correlation = 0.6709)

Issue 4: Clyde and WCofS diet correlation below 0.75

- Crabs and lobsters (0.6709)
- Prawns and shrimp (0.6352)
- Haddock (0.5726)
- Other demersals (0.4141)
- Cod (0.4011)
- Seals (0.3657)
- Whiting (0.2387)

Issue 5: Biomass differences between the Clyde and WCofS models

- Phytoplankton biomass in the Clyde is high (80 $t.km^{-2}$): WCofS estimates using an EE of 0.95
- Other invertebrate biomass is high (33.397 $t.km^{-2}$) and therefore EE is low (0.521): WCofS uses a biomass of 16.080 $t.km^{-2}$ (EE=0.952).
- Cetacean estimate is low (0.027 $t.km^{-2}$) compared to WCofS (0.126 $t.km^{-2}$)
- Seal estimate is high (0.185 $t.km^{-2}$) compared to WCofS (0.047 $t.km^{-2}$)
- Seabirds estimate is low (0.005 $t.km^{-2}$) compared to WCofS (0.025 $t.km^{-2}$)

Biomass differences will only be altered as a last resort as the Clyde estimates may be more indicative of the ecosystem structure in the model area than the estimates for the entire West Coast of Scotland.

Issue 6: Large P/B differences between the Clyde and WCofS models

- Seals (0.07 in Clyde; 0.111 in WCofS)
- Cetaceans (0.09 in Clyde; 0.02 in WCofS)
- Seabirds (0.8 in Clyde; 0.4 in WCofS)
- Crabs and Lobsters (0.78 in Clyde; 0.425 in WCofS)
- Mackerel (1.021 in Clyde; 0.626 in WCofS)
- Sandeels (3 in Clyde; 1.826 in WCofS): biomass estimated in WCofS (EE=0.95); P/B estimated in WCofS (P/Q = 3)
- Cephalopods (3 in Clyde; 1.981 in WCofS)
- Prawns and shrimp (3 in WCofS; 0.871 in Clyde)

Issue 7: Large Q/B differences between the Clyde and WCofS models

- Cetaceans (6.775 in Clyde; 14 in WCofS)
- Seabirds (53.5 in Clyde; 83.051 in WCofS)
- Rays and skates (1.45 in Clyde; 2.243 in WCofS)
- Cod (3.797 in Clyde; 6.112 in WCofS)
- Haddock (4 in Clyde; 7.542 in WCofS)
- Sandeels (10.25 in Clyde; 6.085 in WCofS)
- Cephalopods (10 in Clyde; 15 in WCofS)
- Herring (7 in Clyde; 10.1 in WCofS)
- Prawns and shrimp (12 in Clyde; 5.806 in WCofS): estimated in Clyde with P/Q of 0.25 (calculated P/Q of 0.15 in WCofS).

Step 2: Adjusting the Clyde Model

Diet changes

Diets of functional groups in the Clyde Sea model were altered to ensure that each functional groups diet obtained a minimum correlation coefficient of 0.75 when compared to the corresponding functional group diet in the WCofS model. The WCofS model is a much more 'active' model than the Clyde Sea model, undergoing rigorous and frequent modification to ensure the input and output data is of high quality. As the original Clyde diet matrix was built using values from the Haggan and Pitcher (2005) WCofS model, this method of model balancing is justified, and can largely be seen as a method to update the Clyde Sea data.

- Seal diet was replaced with the WCofS diet, reducing whiting and rays and skates EE whilst increasing the EE of cod and unbalancing the previously balanced haddock group. This change did however reduce the trophic level of seals to 4.441, a value more in keeping with the WCofS estimate.
- The diet of cod was replaced with the WCofS diet. This had little consequence to the immediate structure of the model.
- Whiting diet was replaced with the WCofS diet, balancing the EE of rays and skates and reducing the TL of whiting from 4.069 to 3.386.
- The diet of haddock was replaced with the WCofS diet, reducing its trophic level from 3.484 to 3.115.
- The diets of other demersals, prawns and shrimp, crabs and lobsters and seabirds were also replaced with WCofS estimates, as all groups had large discrepancies from the WCofS model. The diet of crabs and lobsters could not be 100% replicated as a large part of their diet in the WCofS is algae, a functional group not included in the Clyde model. The diet of crabs and lobsters was summed to 1 to reallocate the remaining diet proportion.

P/B, Q/B and biomass changes

P/B and Q/B ratios for functional groups in the Clyde Sea should resemble those of the WCofS. Similarly to diet balancing, P/B and Q/B values were used from the WCofS to update and balance the Clyde Sea model.

- Seal and Cetacean P/B and Q/B was updated using WCofS estimates.
- Cod Q/B was raised from 3.797 $year^{-1}$ (Clyde) to 6.112 $year^{-1}$ (WCofS), reducing the P/Q from 0.316 to 0.196.
- Rays and skates Q/B was raised from 1.45 $year^{-1}$ (Clyde) to 2.243 $year^{-1}$ (WCofS), reducing P/Q from 0.331 to 0.214.

- Cephalopod Q/B was raised from 10 year^{-1} (Clyde) to 15 year^{-1} (WCofS), reducing P/Q from 0.3 to 0.2.
- Seabird P/B and Q/B was updated using WCofS estimates. This initially led to an EE of 1.21, unbalancing Seabirds. Generally we can expect seabirds to have a relatively low EE as they are not directly fished and have few predators. The unbalanced EE was a result of high consumption mortality from sharks. According to the Clyde diets, seabirds accounted for 40% of sharks diets. This is unrealistic and therefore the diets of sharks were updated using WCofS values. This reduced Seabird EE from 1.21 to 0.185, a much more realistic value.
- Cod P/B was increased from 1.2 year^{-1} (Clyde) to 1.644 year^{-1} (WCofS), moving us closer to balancing this group by reducing its EE from 1.75 to 1.29.
- Haddock P/B was increased from 1 year^{-1} (Clyde) to 1.37 year^{-1} (WCofS) and haddock Q/B was raised from 4 year^{-1} (Clyde) to 7.542 year^{-1} (WCofS). These adjustments reduced haddocks EE from 1.9 to 1.45.
- During the balancing process the EE of large zooplankton exceeded 1. To balance this group we now estimate biomass using an EE of 0.95, as done in the WCofS. For uniformity this approach was also applied to small zooplankton.
- The biomass of Seals in the Clyde model (0.185 t.km^{-2}) is much larger than the WCofS estimate (0.047 t.km^{-2}). Seals predate upon the remaining unbalanced groups (cod, haddock and whiting) and therefor this heavy top-down pressure is partly responsible for the imbalance in the model. By using the WCofS biomass we reduced cod EE from 1.286 to 1.089, haddock EE from 1.449 to 1.255 and whiting EE from 1.341 to 1.211.
- The EE of mackerel in the model resided at 0.5, a particularly low value for a pelagic species such as mackerel. Mackerel P/B was therefore reduced from 1.021 year^{-1} (Clyde) to 0.626 year^{-1} (WCofS), increasing mackerel EE to a more realistic value of 0.939.
- The biomass of haddock in the Clyde Sea (0.3 t.km^{-2}) was much lower than the WCofS estimate (0.979 t.km^{-2}). Replacing haddock's biomass with the WCofS value balanced the group but resulted in an unrealistically low EE estimate. Instead, we chose to provide an EE of 0.95 and allow the model to estimate a biomass. The biomass of haddock was estimated to be 0.404 t.km^{-2}.
- The biomass of cod was increased from 0.432 t.km^{-2} (Clyde) to 0.56 t.km^{-2} (WCofS), balancing cod with an EE of 0.814.
- The biomass of whiting was increased from 0.645 t.km^{-2} (Clyde) to 0.785 t.km^{-2} (WCofS), balancing whiting with an EE of 0.995.
- Further changes made to update the ecological coherence of the model include:

- Increasing Cephalopod P/B from 3 $year^{-1}$ (Clyde) to 1.981 $year^{-1}$ (WCofS)
- Reducing crab and lobster P/B from 0.78 $year^{-1}$ (Clyde) to 0.425 $year^{-1}$ (WCofS)
- Estimating the biomass and P/B of sandeels (as seen in the WCofS model) using a Q/B of 6.085 $year^{-1}$ (WCofS; in place of Clyde 10.25 $year^{-1}$ estimate), an EE of 0.95 and a P/Q of 0.3 (WCofS).
- Increasing herring Q/B from 7 $year^{-1}$ (Clyde) to 10.1 $year^{-1}$ (WCofS).

Balanced model

As a result of the model balancing process, all EE estimates fall below 1, the P/Q estimates of poikliotherms fall within the ecological limits of 0.1 and 0.3 and functional group trophic levels, P/B's, Q/B's and diets show greater agreement with the WCofS model. Basic estimates for the balanced Clyde Sea model can be found in Table 11 and the accompanying diet in Table 12. Rerunning PREBAL diagnostics show that biological ratios still follow the expected trends with increasing trophic level, with fewer groups diverting from both the trend line and WCofS estimates. PREBAL diagnostics for trophic level, biomass, P/B, Q/B and P/Q can be found in Figures 7, 8, 9, 10 and 11 respectively.

	Functional group	TL	B ($t.km^{-2}$)	P/B ($year^{-1}$)	Q/B ($year^{-1}$)	EE	P/Q
1	Seals	4.364	0.047	0.111	12.000	0.000	0.009
2	Cetaceans	4.074	0.126	0.090	14.000	0.000	0.006
3	Birds	4.150	0.005	0.400	83.051	0.864	0.005
4	Sharks	4.052	0.682	0.600	3.000	0.653	0.200
5	Rays and skates	3.799	1.400	0.480	2.243	0.084	0.214
6	Cod	3.417	0.560	1.644	6.112	0.814	0.269
7	Haddock	3.148	0.384	1.370	7.542	0.950	0.182
8	Saithe	3.972	0.505	0.870	4.023	0.631	0.216
9	Whiting	3.402	0.785	1.450	5.460	0.995	0.266
10	Other demersals	3.419	2.622	0.816	2.726	0.950	0.299
11	Flatfish	3.277	1.785	0.929	3.097	0.950	0.300
12	Mackerel	3.334	0.835	0.626	3.950	0.972	0.158
13	Herring	3.187	1.827	1.800	10.100	0.950	0.178
14	Sandeels	3.328	0.849	1.826	6.085	0.950	0.300
15	Other pelagic	3.310	9.806	1.216	4.958	0.377	0.245
16	Crabs and lobsters	3.112	1.077	0.425	2.833	0.950	0.150
17	Nephrops	3.106	4.493	0.730	4.867	0.976	0.150
18	Prawns and shrimp	2.645	16.321	3.000	12.000	0.451	0.250
19	Cephalopods	3.198	0.446	1.981	15.000	0.950	0.132
20	Other invertebrates	2.133	33.397	10.556	41.224	0.689	0.256
21	Large zooplankton	2.112	9.686	9.731	35.269	0.950	0.276
22	Small zooplankton	2.031	5.389	18.000	72.000	0.950	0.250
23	Phytoplankton	1.000	80.000	70.000	0.000	0.159	
24	Detritus	1.000	100.000			0.000	

Table 11. *Basic estimates for the condensed 1985 Ecopath model of the Clyde Sea post balancing. Basic estimates include trophic level (TL), biomass (B), production/biomass (P/B), consumption/ biomass (P/Q), ecotrophic efficiency (EE) and production/consumption (P/Q). Parameters estimated by the model are in blue.*

Table 12. Diet matrix for the condensed Ecopath model of the Clyde sea, post balancing.

	Seals	Cetaceans	Seabirds	Sharks	Rays and skates	Cod	Haddock	Saithe	Whiting	Other demersals	Flatfish
Seabirds		0.001									
Sharks		0.000		0.042							0.000
Rays and skates				0.010		0.000				0.000	
Cod	0.087	0.002	0.027	0.021		0.033		0.052	0.006	0.002	0.001
Haddock	0.048	0.000	0.006	0.007		0.028	0.003	0.037	0.003	0.001	0.002
Saithe	0.047	0.001	0.007	0.001					0.002	0.001	
Whiting	0.071	0.001	0.003	0.030		0.037			0.016	0.007	0.009
Other demersals	0.170	0.069	0.052	0.048	0.015	0.005	0.020	0.200	0.007	0.046	0.002
Flatfish	0.077			0.010	0.041	0.012		0.029	0.000	0.008	
Mackerel	0.004	0.001	0.030	0.017		0.002			0.042	0.030	
Herring	0.059	0.001	0.356	0.301	0.130	0.028	0.000	0.150	0.114	0.017	
Sandeels	0.346	0.076	0.086	0.021	0.050	0.041	0.011	0.030	0.030	0.005	
Other pelagic	0.090	0.642	0.307	0.108	0.050	0.046	0.037	0.162	0.089	0.068	
Crabs and lobsters				0.002	0.024	0.002			0.001	0.000	0.000
Nephrops					0.130	0.004				0.001	0.001
Prawns and shrimp		0.002	0.035	0.110	0.380	0.119	0.171	0.115	0.035	0.131	0.204
Cephalopods	0.002	0.005		0.120		0.006		0.005	0.010	0.007	0.021
Other invertebrates		0.000	0.071	0.111	0.180	0.183	0.226		0.121	0.139	0.748
Large zooplankton		0.129	0.020	0.041		0.246	0.313	0.220	0.305	0.537	0.012
Small zooplankton		0.070				0.174	0.094		0.135	0.000	
Phytoplankton						0.035	0.125		0.084		

	Mackerel	Herring	Sandeels	Other pelagic	Crabs and lobsters	Nephrops	Prawns and shrimp	Cephalopods	Other invertebrates	Large zooplankton	Small zooplankton
Cod	0.005										
Haddock	0.007			0.002				0.004			
Whiting	0.011										
Other demersals	0.017			0.004			0.001	0.006			
Flatfish			0.001	0.019	0.016			0.016			
Herring	0.020			0.007				0.019			
Sandeels	0.010	0.000		0.007				0.019			
Other pelagic	0.040	0.000		0.020				0.025			
Crabs and lobsters					0.025			0.002			
Nephrops				0.025			0.001	0.002			
Prawns and shrimp	0.185	0.154	0.403	0.180	0.329		0.010				
Cephalopods				0.007							
Other invertebrates	0.005		0.001	0.131	0.425	0.339	0.373	0.024	0.106		
Large zooplankton	0.600	0.838	0.594	0.565		0.499	0.084	0.604		0.007	
Small zooplankton	0.100		0.001	0.033	0.000	0.161	0.105	0.279	0.012	0.101	0.030
Phytoplankton		0.007					0.100		0.216	0.773	0.800
Detritus					0.205		0.326		0.666	0.119	0.170

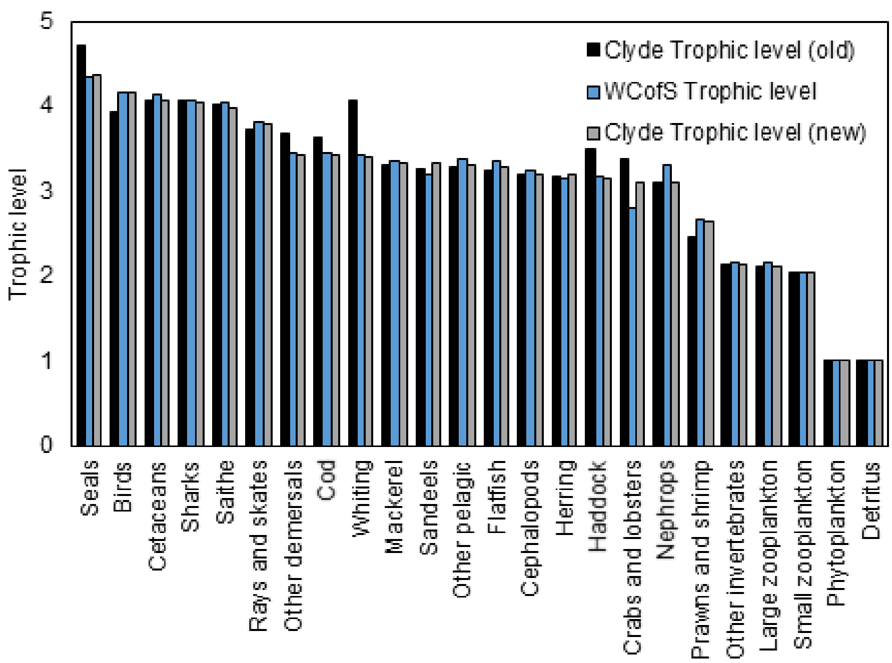


Figure 7. Comparison of the trophic levels of functional groups in the condensed Ecopath models of the Clyde Sea and West Coast of Scotland. Clyde Sea estimates are included for the unbalanced (old) and balanced (new) models.

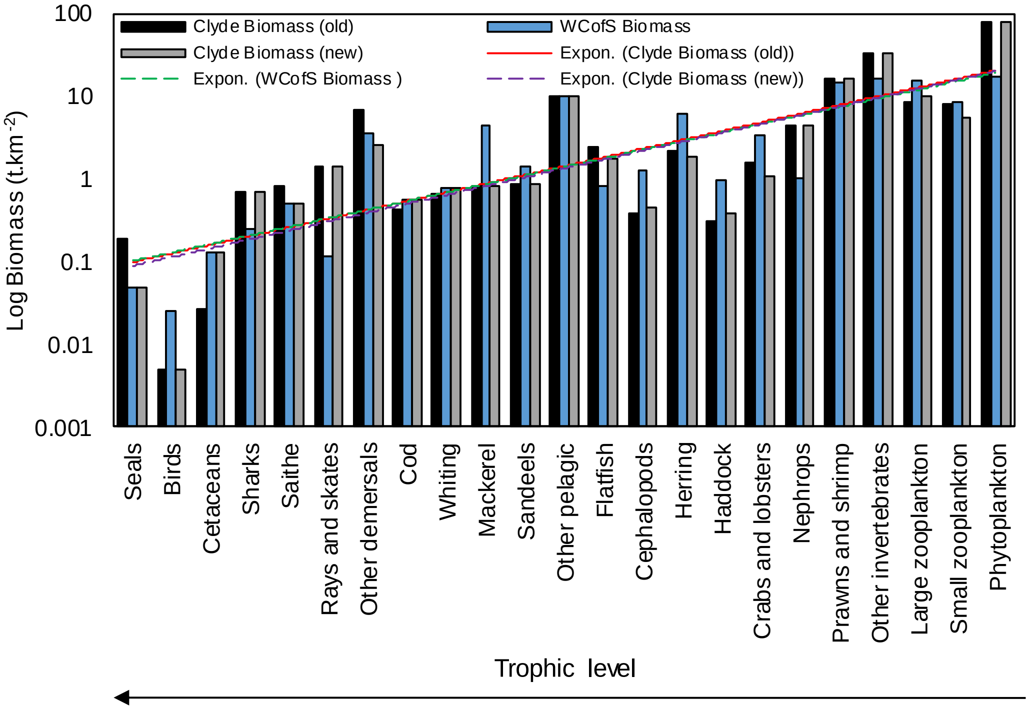


Figure 8. Comparison of the estimated biomasses of functional groups in the condensed Ecopath models of the Clyde Sea and West Coast of Scotland. Trophic level increases from right to left using Clyde Sea estimates. Clyde Sea estimates are included for the unbalanced (old) and balanced (new) models.

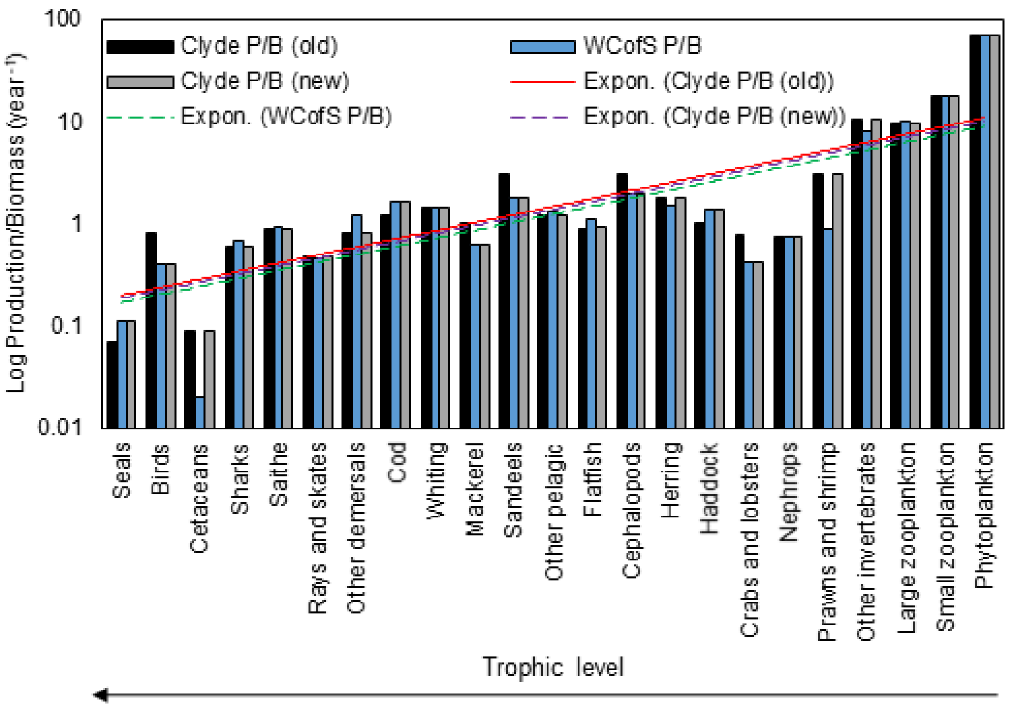


Figure 9. Comparison of the production/biomass ratios of the functional groups in the condensed Ecopath models of the Clyde Sea and West Coast of Scotland. Trophic level increases from right to left using Clyde Sea estimates. Clyde Sea estimates are included for the unbalanced (old) and balanced (new) models.

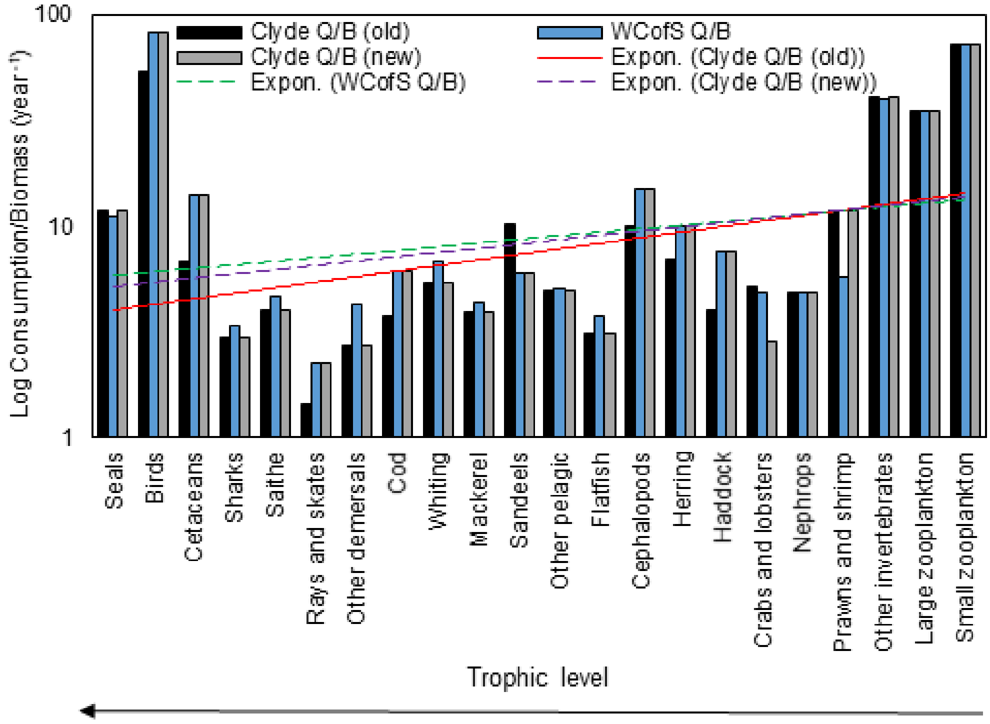


Figure 10. *Comparison of the consumption/biomass ratios of the functional groups in the condensed Ecopath models of the Clyde Sea and West Coast of Scotland. Trophic level increases from right to left using Clyde Sea estimates. Clyde Sea estimates are included for the unbalanced (old) and balanced (new) models.*

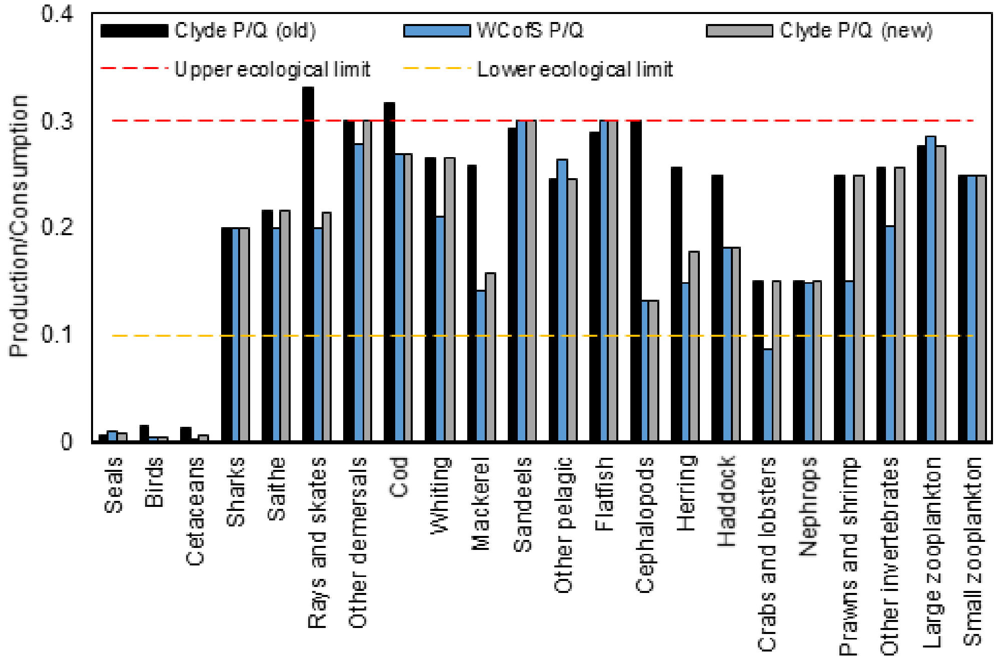


Figure 11. *Comparison of the consumption/production ratios of the functional groups in the condensed Ecopath models of the Clyde Sea and West Coast of Scotland, including the lower (0.1) and upper (0.3) ecological limits. Clyde Sea estimates are included for the unbalanced (old) and balanced (new) models.*

Comparing the diets of the balanced Clyde and WCofS models

After balancing the Clyde Sea Ecopath model all 22 consumer functional groups share high correlation (>0.75) when compared to the diets of the same functional groups in the condensed WCofS model (Table 13). The full diets can be found in Figure 12.

Table 13. *Correlation between functional group diets in the balanced Clyde Sea and West Coast of Scotland Ecopath models.*

Funtional group	Correlation
Seals	1.0000
Seabirds	1.0000
Sharks	1.0000
Haddock	1.0000
Whiting	1.0000
Other demersals	1.0000
Prawns and shrimp	1.0000
Small zooplankton	1.0000
Cephalopods	0.9998
Cetaceans	0.9997
Cod	0.9995
Large zooplankton	0.9972
Saithe	0.9897
Herring	0.9851
Flatfish	0.9655
Mackerel	0.9514
Other pelagic	0.9349
Rays and skates	0.9137
Sandeels	0.8492
Other invertebrates	0.8221
Crabs and lobsters	0.7845
Nephrops	0.7755

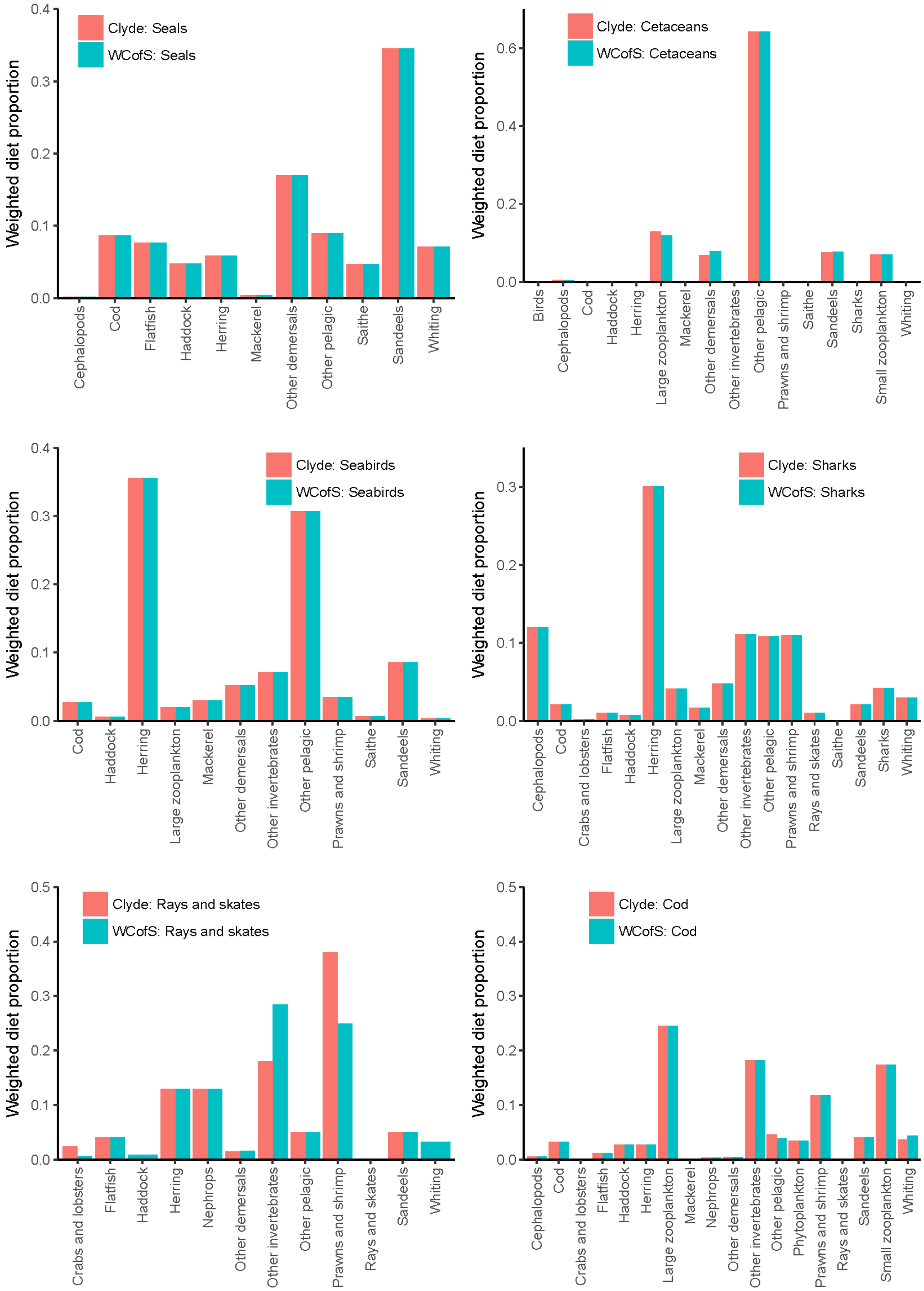


Figure 12. Comparisons of the diets of functional groups included in balanced Clyde sea and West Coast of Scotland Ecopath models.

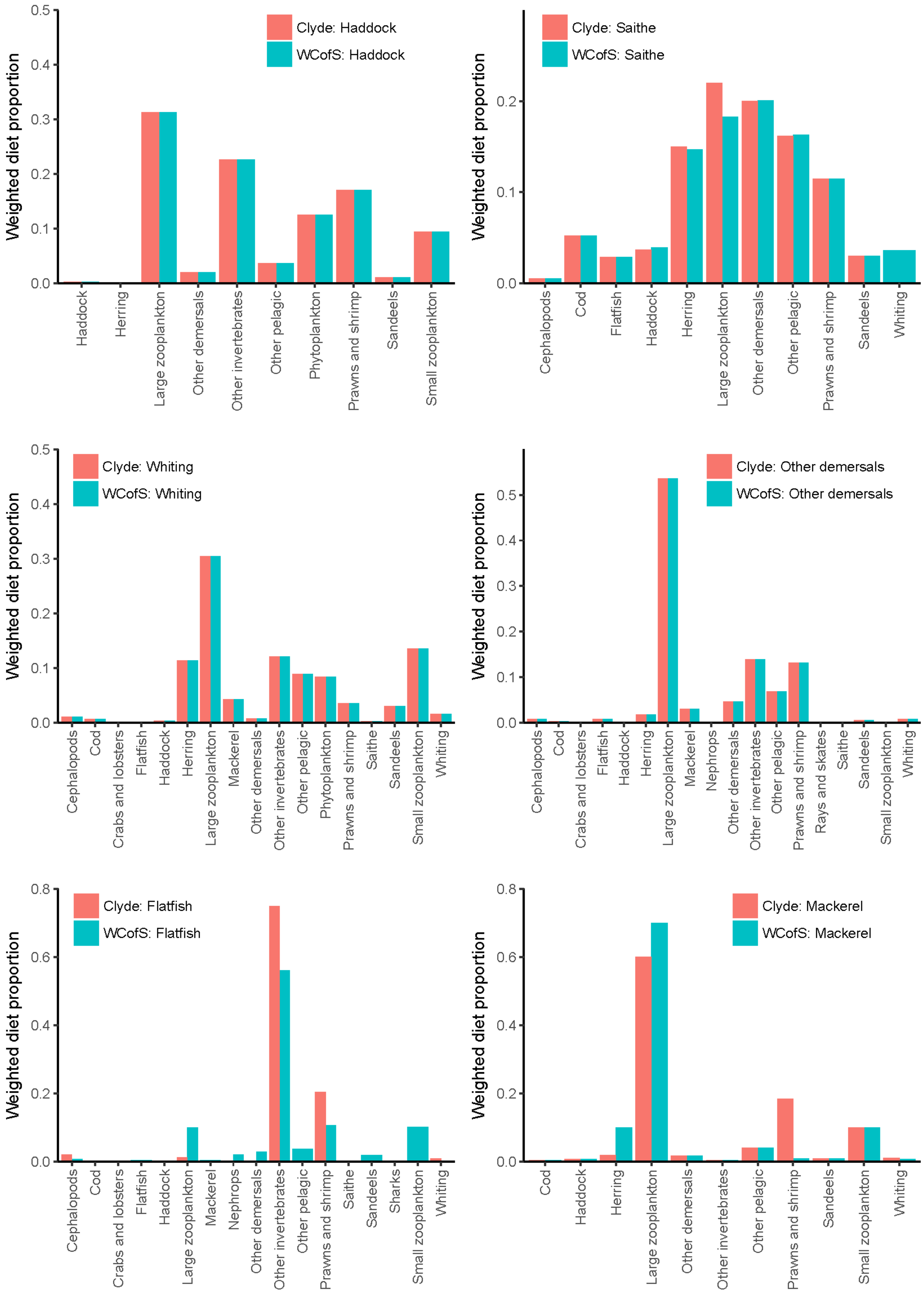


Figure 12. continued

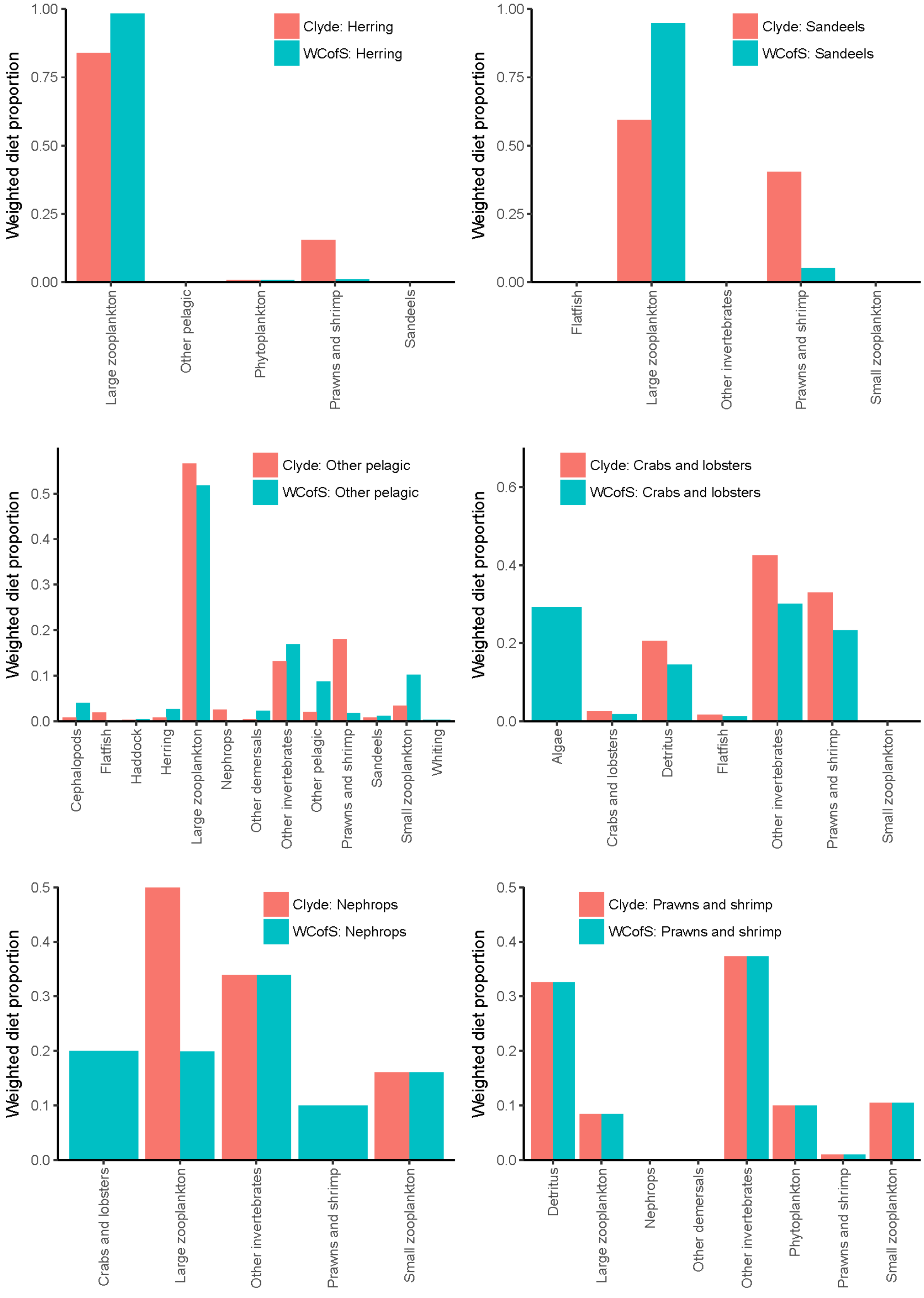


Figure 12. continued

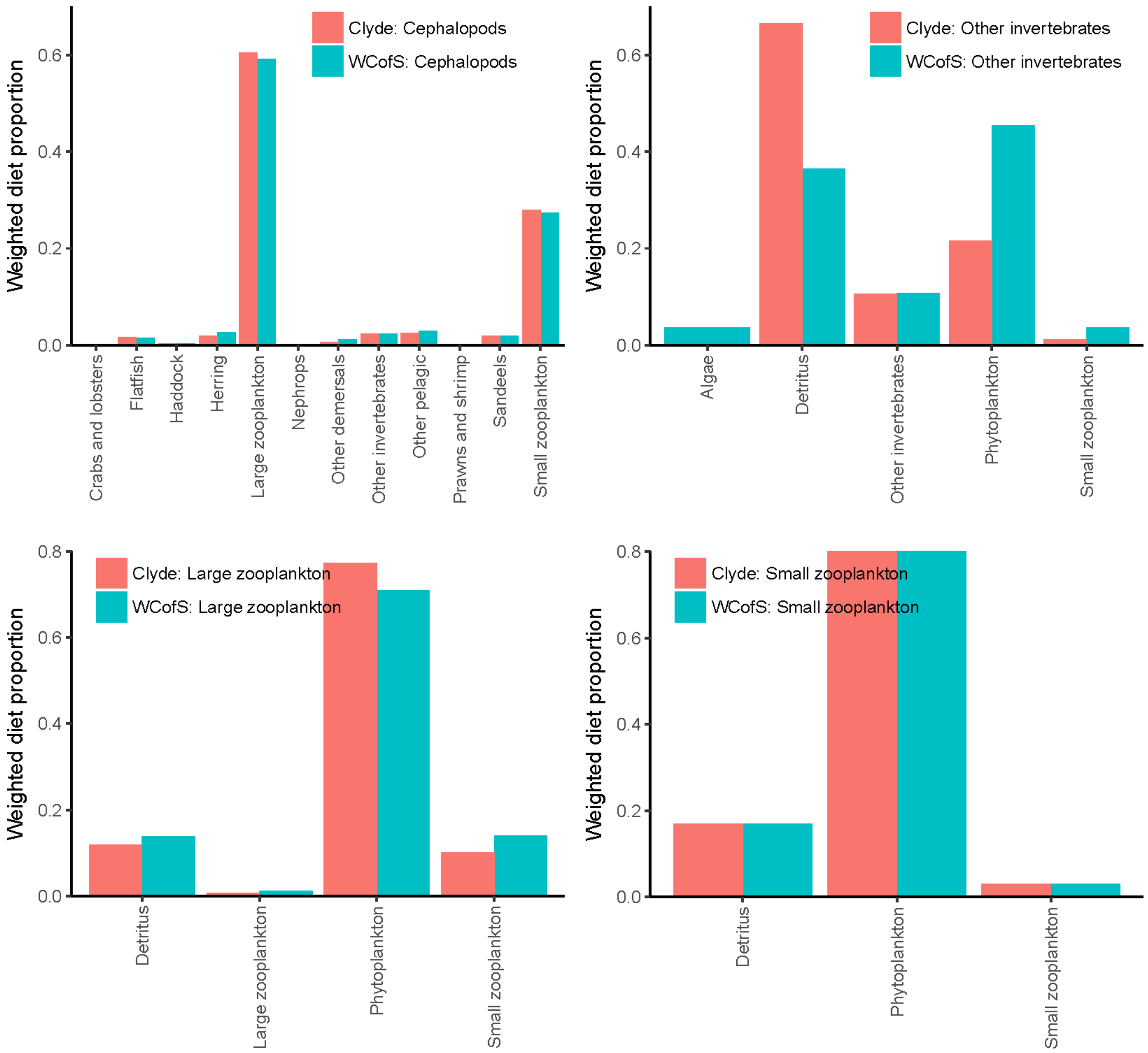


Figure 12. continued

Ecosim

Input Data

The EwE model of the Clyde Sea includes six relative biomass time series (Figure 13), six catch time series (Figure 14), six fishing mortality time series (Figure 15) and 15 forced catch time series (Figure 16). Fishery landings statistics, specifically for the Clyde area, were provided by the Marine Fisheries Agency (UK) from 1985 to 2008. During the construction of the original Clyde Sea EwE model, researchers used fishing mortality time series for the whole of ICES area VIa (West Coast of Scotland) to drive catches and biomass predictions within the Clyde Sea. In our investigation we therefore also utilise the more recently updated fishing mortality time series from the WCofS model to drive biomass and catch in the Clyde Sea model (Figure 17). Model predictions will be compared on the basis of which fishing mortality driver was used to determine the best fitting method.

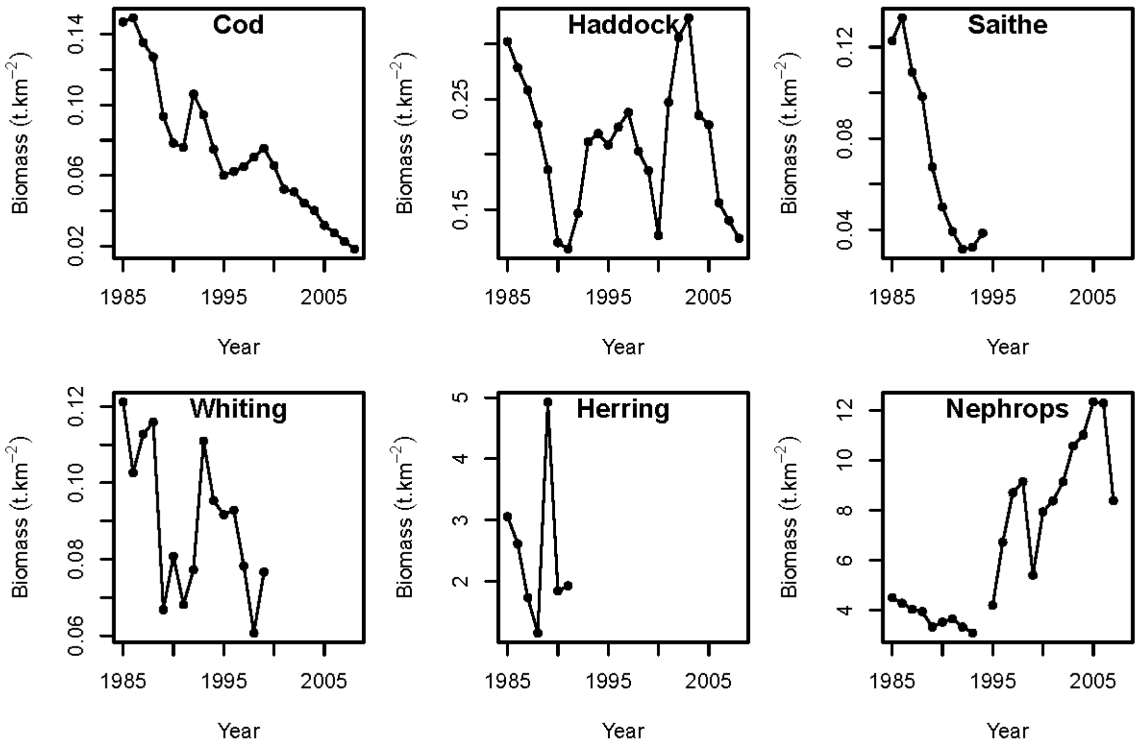


Figure 13. Relative biomass time series assigned to functional groups and used as validation data during Ecosim simulations of the Clyde Sea (1985-2008).

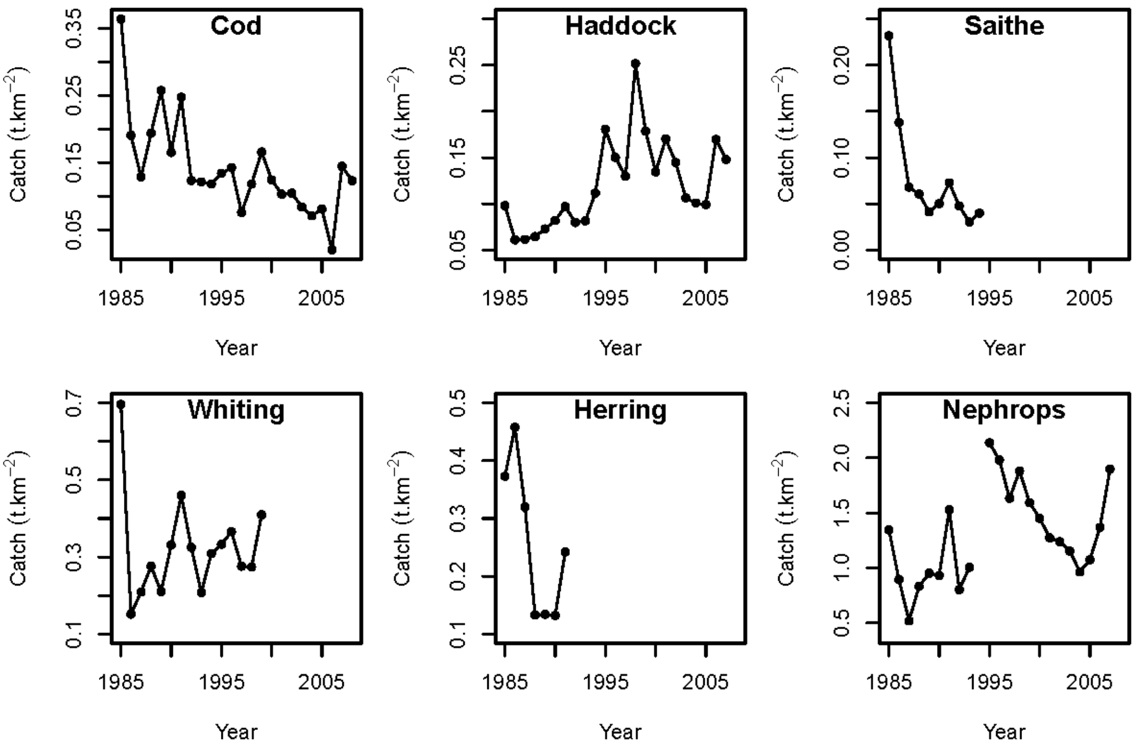


Figure 14. Catch time series assigned to functional groups and used as validation data during Ecosim simulations of the Clyde Sea (1985-2008).

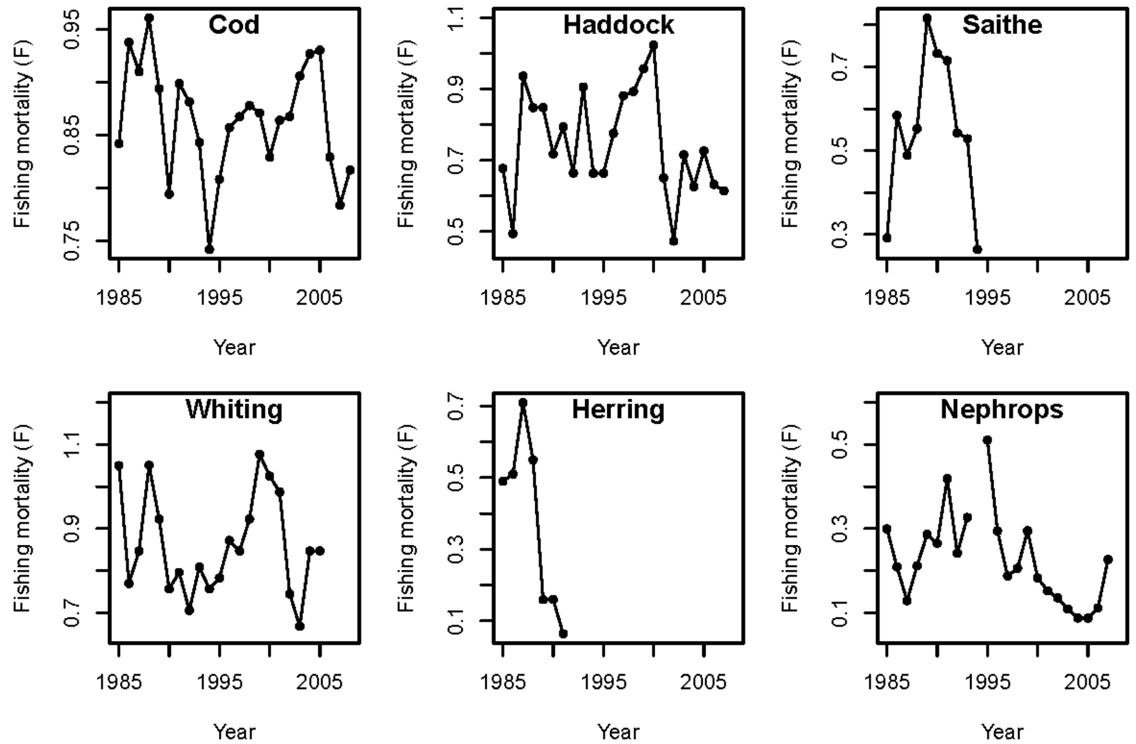


Figure 15. Fishing mortality (F) time series assigned to functional groups and used as driving data during Ecosim simulations of the Clyde Sea (1985-2008).

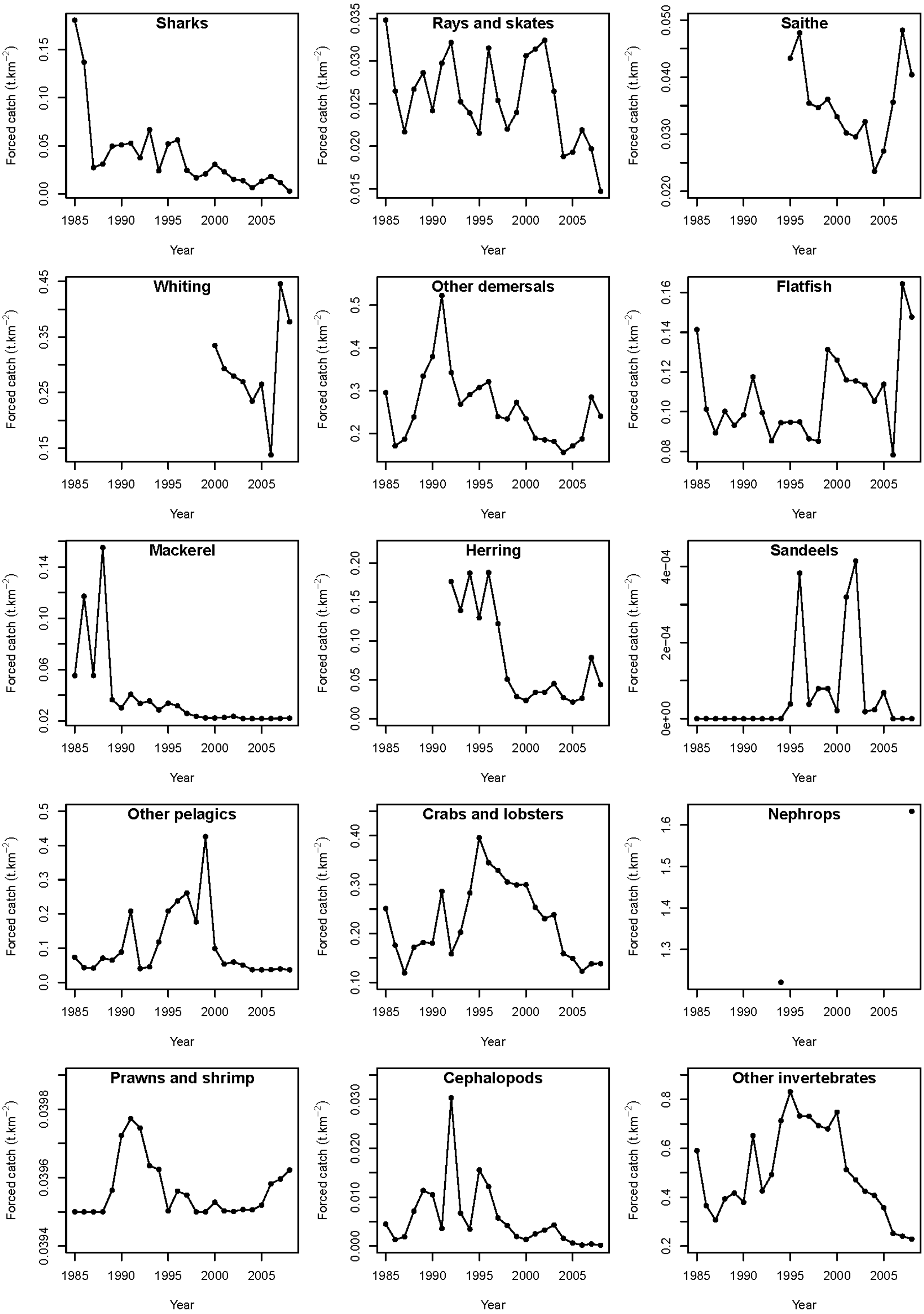


Figure 16. Biomass time series assigned to functional groups and used as driving data during Ecosim simulations of the Clyde Sea (1985-2008).

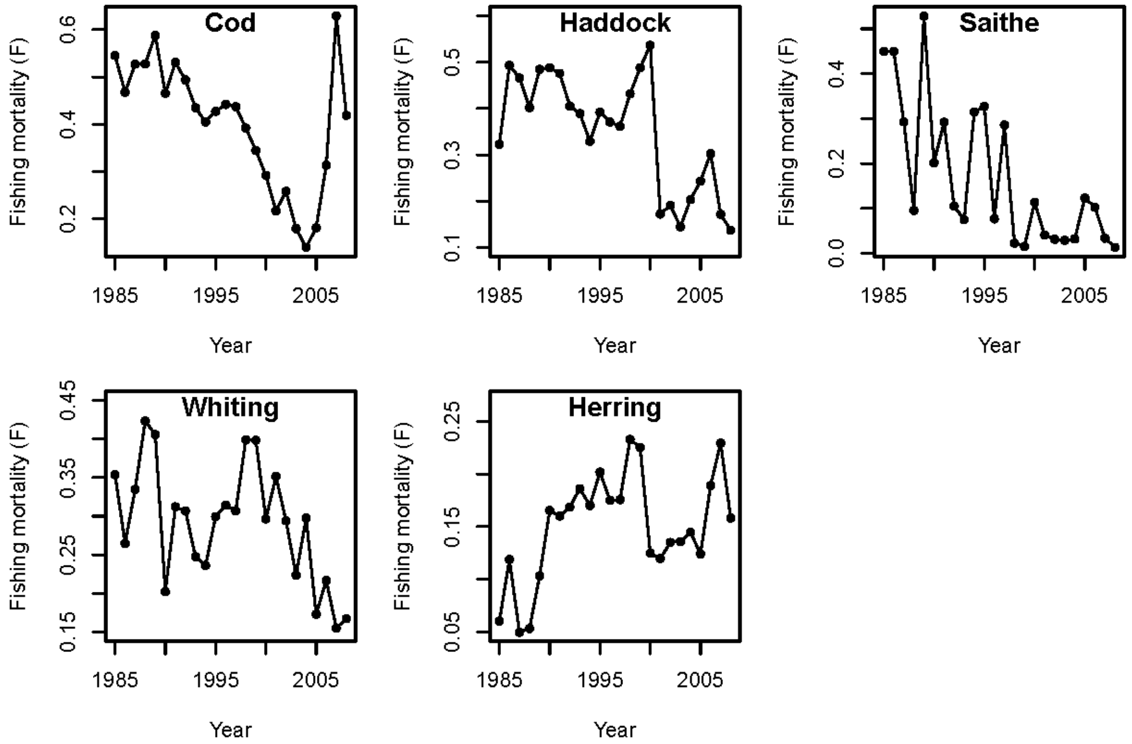


Figure 17. Fishing mortality (F) time series assigned to functional groups in the West Coast of Scotland Ecopath with Ecosim model.

Stepwise fitting

Model predictions were fitted to the observed catch and biomass time series using EwE's automated stepwise fitting procedure. With 12 validation time series entered into the model, a maximum of 11 parameters were estimated to increase the fit of model predictions. The parameters estimated include vulnerabilities (top-down/bottom-up trophic interactions) and primary production (PP) anomaly spline points. The model fitting procedure was run four times under different fitting hypothesis:

- **Run 1:** Fishing (Clyde Sea F), vulnerabilities (predator/prey), PP anomaly (≤5 spline points)
- **Run 2:** Fishing (Clyde Sea F), vulnerabilities (predator), PP anomaly (≤5 spline points)
- **Run 3:** Fishing (WCofS F), vulnerabilities (predator/prey), PP anomaly (≤5 spline points)
- **Run 4:** Fishing (WCofS F), vulnerabilities (predator), PP anomaly (≤5 spline points)

The best fitted models based on AICc for fitting Runs 1,2,3 and 4 can be found in Table 14, 15, 16 and 17 respectively. The best models from runs 2, 3 and 4 all estimate five vulnerabilities and a PP anomaly with four spline points. The best model from Run 1 estimates 11 vulnerability parameters. Table 18 presents a breakdown of each functional groups contribution towards the sum of squares of the best fitting models from Runs 1-4.

Stepwise fitting model iterations

Model Iteration	K	V's	PP	SS	AIC	AICc	ΔAICc
Fishing and 11v	11	11	0	62.930	-214.367	-213.215	0.000
Fishing and 10v	10	10	0	64.552	-211.438	-210.501	2.715
Fishing and 9v	9	9	0	66.927	-206.318	-205.572	7.643
Fishing and 8v	8	8	0	69.128	-201.940	-201.363	11.852
Fishing and 7v + 2pp	9	7	2	78.832	-173.082	-172.336	40.879

*Table 14. Clyde Sea Ecosim model iterations with the lowest AICc scores using **Run 1** hypothesis': Fishing, vulnerabilities (predator/prey), PP anomaly (≤5 spline points). The table includes the number of parameter estimates (K) and how these were distributed between vulnerability estimates (V's) and primary production anomaly spline points (PP)*

Model Iteration	K	V's	PP	SS	AIC	AICc	ΔAICc
Fishing and 5v + 4pp	9	5	4	43.820	-292.292	-291.546	0.000
Fishing and 5v + 3pp	8	5	3	44.481	-291.442	-290.864	0.682
Fishing and 5v + 5pp	10	5	5	44.484	-287.022	-286.085	5.461
Fishing and 4v + 2pp	6	4	2	48.444	-278.428	-278.122	13.424
Fishing and 4v + 3pp	7	4	3	47.966	-278.297	-277.866	13.680

*Table 15. Clyde Sea Ecosim model iterations with the lowest AICc scores using **Run 2** hypothesis': Fishing, vulnerabilities (predator), PP anomaly (≤5 spline points). The table includes the number of parameter estimates (K) and how these were distributed between vulnerability estimates (V's) and primary production anomaly spline points (PP)*

Model Iteration	K	V's	PP	SS	AIC	AICc	ΔAICc
Fishing and 5v + 4pp	9	5	4	51.254	-260.480	-259.734	0.000
Fishing and 7v + 4pp	11	7	4	50.994	-257.063	-255.912	3.822
Fishing and 5v + 5pp	10	5	5	51.888	-255.772	-254.834	4.900
Fishing and 5v + 2pp	7	5	2	54.856	-251.050	-250.619	9.115
Fishing and 4v + 5pp	9	4	5	53.707	-250.988	-250.242	9.492

*Table 16. Clyde Sea Ecosim model iterations with the lowest AICc scores using **Run 3** hypothesis': Fishing (WCofS fishing mortality), vulnerabilities (predator/prey), PP anomaly (≤5 spline points). The table includes the number of parameter estimates (K) and how these were distributed between vulnerability estimates (V's) and primary production anomaly spline points (PP).*

Model Iteration	K	V's	PP	SS	AIC	AICc	ΔAICc
Fishing and 5v + 4pp	9	5	4	47.001	-278.064	-277.318	0.000
Fishing and 5v + 5pp	10	5	5	46.494	-278.052	-277.114	0.204
Fishing and 6v + 4pp	10	6	4	46.657	-277.341	-276.404	0.914
Fishing and 6v + 5pp	11	6	5	46.173	-277.221	-276.069	1.249
Fishing and 7v + 4pp	11	7	4	46.656	-275.109	-273.957	3.361

*Table 17. Clyde Sea Ecosim model iterations with the lowest AICc scores using **Run 4** hypothesis': Fishing (WCofS fishing mortality), vulnerabilities (predator), PP anomaly (≤5 spline points). The table includes the number of parameter estimates (K) and how these were distributed between vulnerability estimates (V's) and primary production anomaly spline points (PP).*

Time series	Functional group	Sum of squares (SS)			
		Run 1	Run 2	Run 3	Run 4
Biomass	Cod	1.434	2.680	6.770	6.504
	Haddock	2.210	2.945	1.788	1.388
	Saithe	0.685	0.291	2.829	1.991
	Whiting	0.959	1.070	0.977	0.661
	Herring	1.230	1.711	1.417	1.367
	Nephrops	3.760	1.835	2.209	1.833
Catch	Cod	6.298	6.563	11.978	11.283
	Haddock	7.529	4.737	5.452	6.296
	Saithe	14.825	7.126	8.266	6.065
	Whiting	13.519	9.712	3.108	2.739
	Herring	6.080	3.167	4.227	4.056
	Nephrops	4.394	1.956	2.214	2.791

Table 18. Sum of squares (SS) breakdown showing the capacity the best models (ΔAICc = 0) from four model hypothesis to replicate observed biomass and catch trends for six functional groups in the Clyde Sea Ecopath with Ecosim (EwE) model. Runs 1 and 2 use fishing mortality drivers from the Clyde Sea data set whilst Runs 3 and 4 use fishing mortality drivers from the West Coast of Scotland EwE model. Runs 1 and 3 assign vulnerabilities to specific predator/prey interactions whilst Runs 2 and 4 assign vulnerabilities to predators.

Vulnerabilities and primary production anomalies

All runs suggest the Clyde ecosystem is driven by mixed trophic control (both bottom-up and top-down interactions). The best fitting model (ΔAICc = 0) from Run 1 estimated 11 predator/prey vulnerabilities, assigned across three predators: cod, haddock and saithe (Table 19). Run 2 assigned vulnerabilities to the diets of five predators: sharks, cod, haddock, whiting and Nephrops (Table 20). The best fitting model from Run 2 also included a four spline point primary production anomaly, driving the ecosystem from the bottom-up (Figure 28). Run 3 also estimated five vulnerabilities in the best fisting model, however these were assigned to specific predator/prey interactions (Table 21). The best fitting model from Run 3 also included a four spline point primary production anomaly. Finally Run 4 also estimated 5 vulnerabilities, assigned to the prey of cod, haddock, saithe, whiting and Nephrops (Table 22), as well as a four spline point primary production anomaly.

*Table 19. Clyde Sea Ecosim predator/prey vulnerabilities estimated by the best fit model (ΔAICc = 0) using the **Run 1** hypothesis (Fishing, vulnerabilities (predator/prey), PP anomaly (≤5 spline points)).*

Pred/Prey	Cod	Haddock	Saithe
Cod			2.6006
Haddock			1.9476
Prawns and shrimp	1.00E+10	5.54E+09	
Other invertebrates	1.00E+10	1.00E+10	
Large zooplankton	1.00E+10	1	
Small zooplankton	1.00E+10	72140.53	
Phytoplankton		4400204	

*Table 20. Clyde Sea Ecosim predator/prey vulnerabilities estimated by the best fit model (ΔAICc = 0) using the **Run 2** hypothesis (Fishing, vulnerabilities (predator), PP anomaly (≤5 spline points)).*

Pred/Prey	Sharks	Cod	Haddock	Whiting	Nephrops
Sharks	1.00E+10				
Rays and skates	1.00E+10	8.259315			
Cod	1.00E+10	8.259315		1	
Haddock	1.00E+10	8.259315	2.016581	1	
Saithe	1.00E+10			1	
Whiting	1.00E+10	8.259315		1	
Other demersals	1.00E+10	8.259315	2.016581	1	
Flatfish	1.00E+10	8.259315		1	
Mackerel	1.00E+10	8.259315		1	
Herring	1.00E+10	8.259315	2.016581	1	
Sandeels	1.00E+10	8.259315	2.016581	1	
Other pelagic	1.00E+10	8.259315	2.016581	1	
Crabs and lobsters	1.00E+10	8.259315		1	
Nephrops		8.259315			
Prawns and shrimp	1.00E+10	8.259315	2.016581	1	
Cephalopods	1.00E+10	8.259315		1	
Other invertebrates	1.00E+10	8.259315	2.016581	1	5.974776
Large zooplankton	1.00E+10	8.259315	2.016581	1	5.974776
Small zooplankton		8.259315	2.016581	1	5.974776
Phytoplankton		8.259315	2.016581	1	

*Table 21. Clyde Sea Ecosim predator/prey vulnerabilities estimated by the best fit model (ΔAICc = 0) using the **Run 3** hypothesis (Fishing (WCofS fishing mortality), vulnerabilities (predator/prey), PP anomaly (≤5 spline points)).*

Pred/Prey	Haddock	Saithe	Whiting	Nephrops
Cod		1.00E+10		
Haddock		1.028572		
Large zooplankton	2.122047		1.000002	1907168

*Table 22. Clyde Sea Ecosim predator/prey vulnerabilities estimated by the best fit model (ΔAICc = 0) using the **Run 4** hypothesis (Fishing (WCofS fishing mortality), vulnerabilities (predator), PP anomaly (≤5 spline points)).*

Pred/Prey	Cod	Haddock	Saithe	Whiting	Nephrops
Rays and skates	1				
Cod	1		1	1.003016	
Haddock	1	1.990042	1	1.003016	
Saithe				1.003016	
Whiting	1			1.003016	
Other demersals	1	1.990042	1	1.003016	
Flatfish	1		1	1.003016	
Mackerel	1			1.003016	
Herring	1	1.990042	1	1.003016	
Sandeels	1	1.990042	1	1.003016	
Other pelagic	1	1.990042	1	1.003016	
Crabs and lobsters	1			1.003016	
Nephrops	1				
Prawns and shrimp	1	1.990042	1	1.003016	
Cephalopods	1		1	1.003016	
Other invertebrates	1	1.990042		1.003016	71.70874
Large zooplankton	1	1.990042	1	1.003016	71.70874
Small zooplankton	1	1.990042		1.003016	71.70874
Phytoplankton	1	1.990042		1.003016	

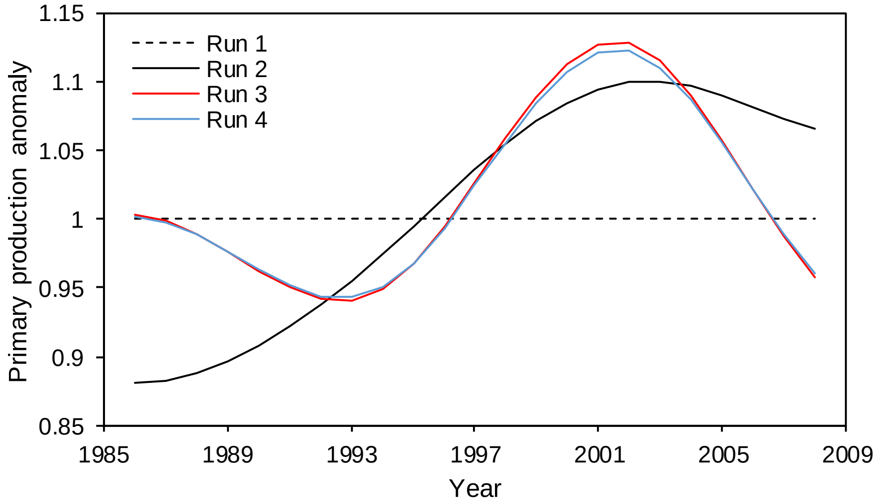


***Figure 18.** Primary production (PP) anomalies estimated for the best fit models (ΔAICc = 0) from four model hypothesis (Runs 1-4).*

Clyde Sea Ecosim projections: 1

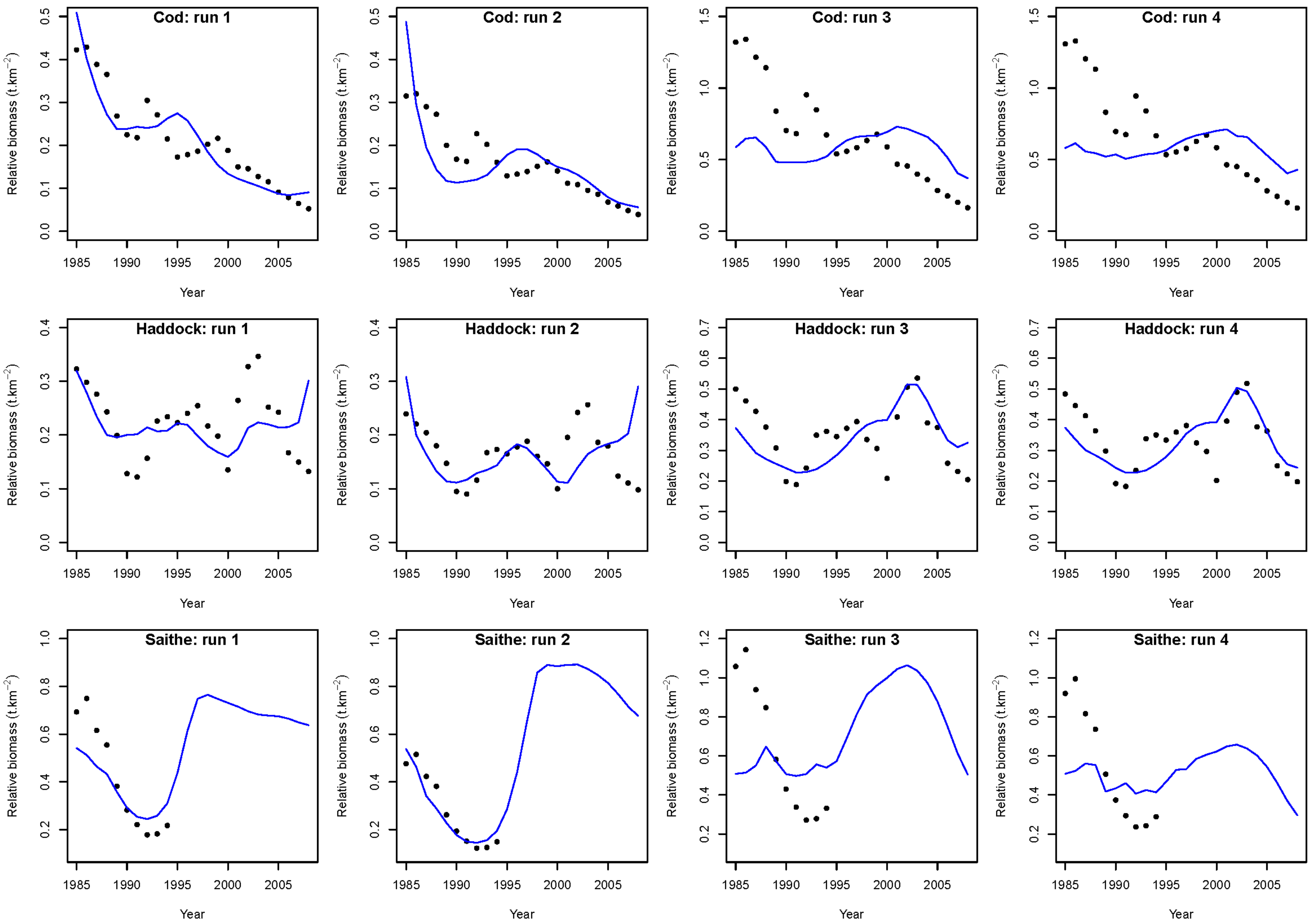
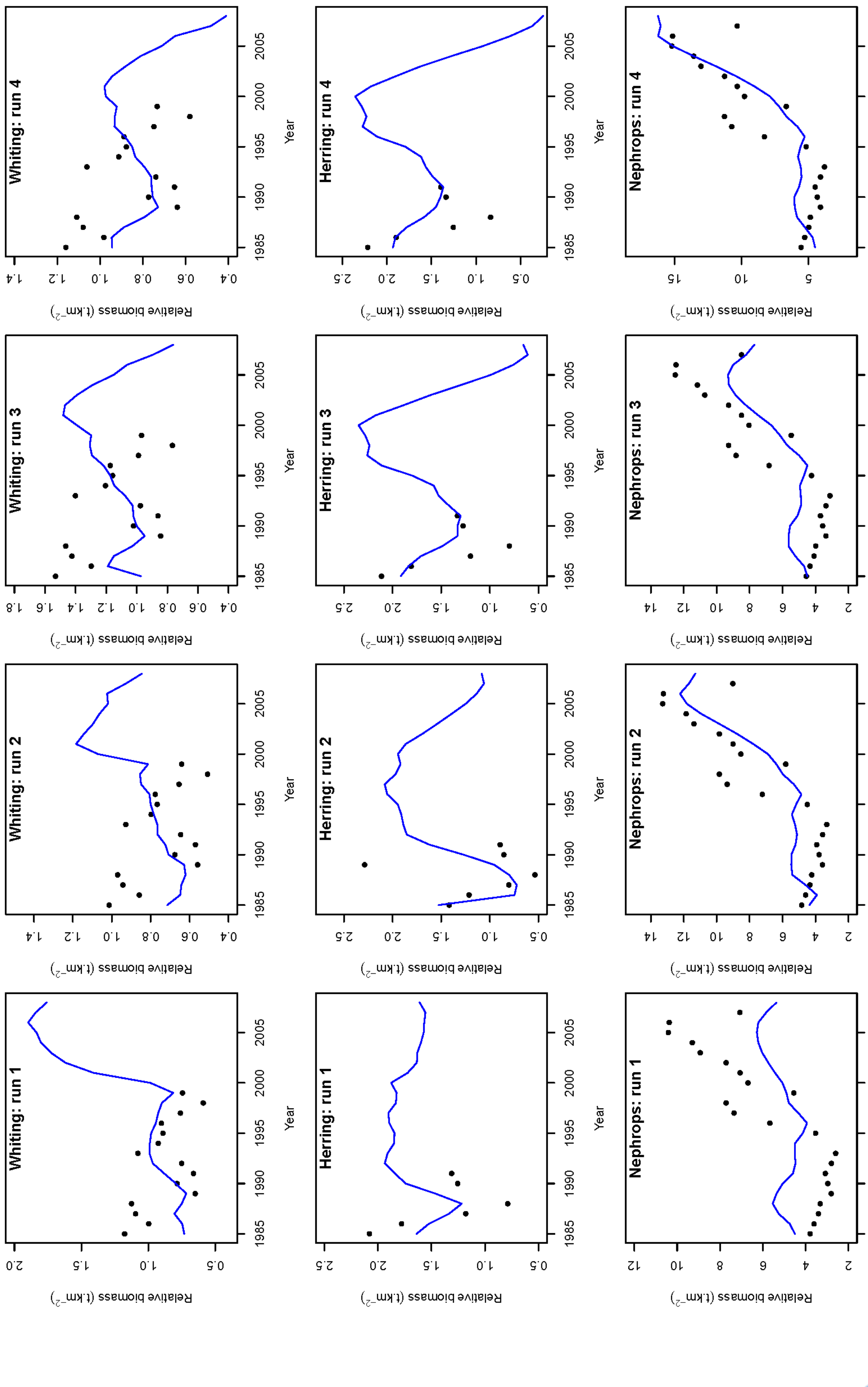


Figure 19. *Observed (black dots) and predicted (blue lines) relative biomass trends for functional groups in the Clyde Sea Ecopath with Ecosim model. Model simulations were run under four sets of hypothesis (Runs 1-4). Runs 1 and 2 use fishing mortality drivers from the Clyde Sea data set whilst Runs 3 and 4 use fishing mortality drivers from the West Coast of Scotland EwE model. Runs 1 and 3 assign vulnerabilities to specific predator/prey interactions whilst Runs 2 and 4 assign vulnerabilities to predators.*

Figure 19. *continued*



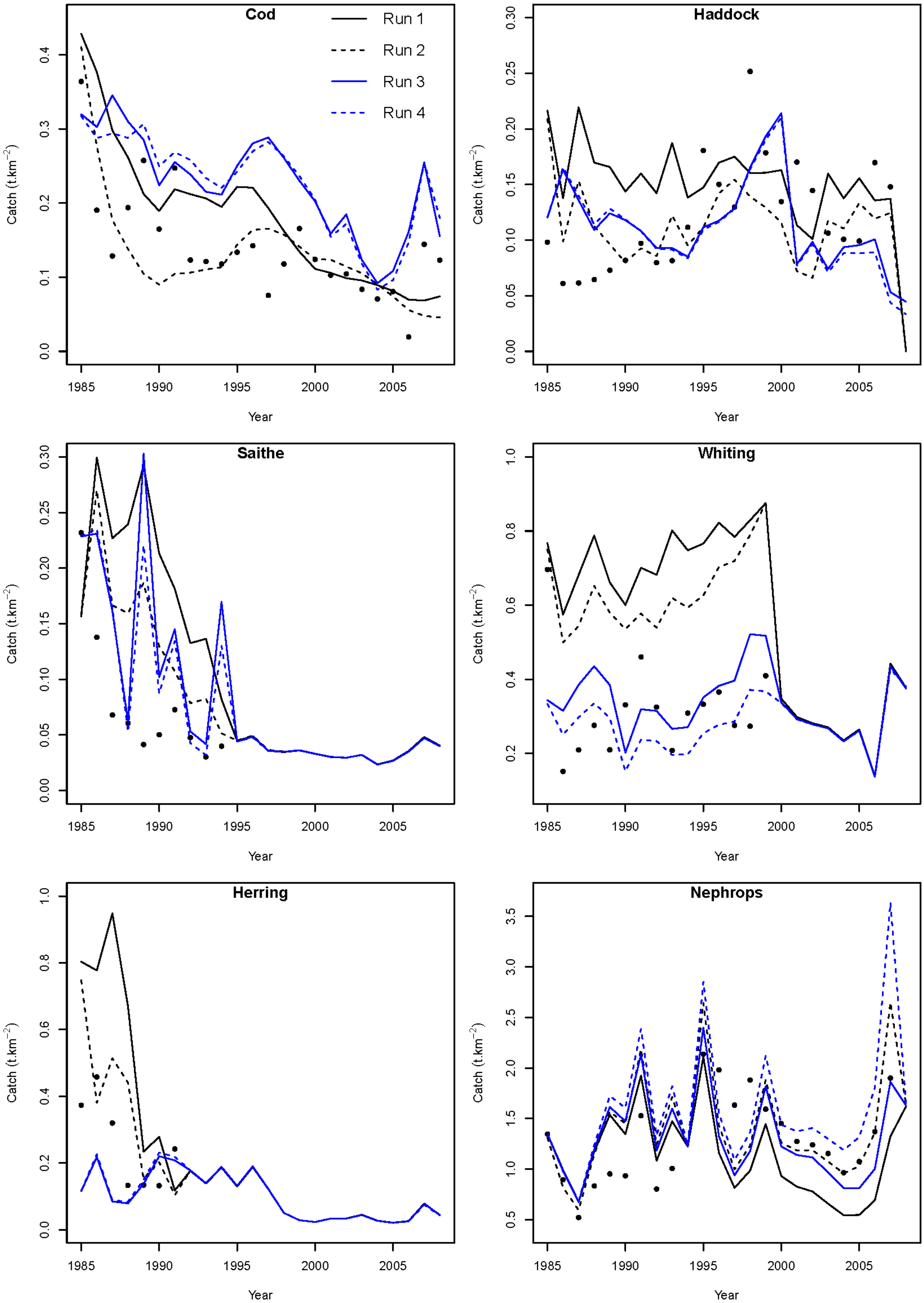


Figure 20. *Observed (black dots) and predicted catch trends for functional groups in the Clyde Sea Ecopath with Ecosim model. Model simulations were run under four sets of hypothesis (Runs 1-4). Runs 1 and 2 use fishing mortality drivers from the Clyde Sea data set whilst Runs 3 and 4 use fishing mortality drivers from the West Coast of Scotland EwE model. Runs 1 and 3 assign vulnerabilities to specific predator/prey interactions whilst Runs 2 and 4 assign vulnerabilities to predators.*

Hybrid runs

Some functional groups show a clear preference for either the original Clyde Sea fishing mortality drivers or the WCofS fishing mortality drivers. Cod and saithe appear to achieve better fits when driven with the Clyde time series, whilst haddock and whiting are better fitted using the WCofS time series'. Herring fit doesn't seem to be better under either time series whilst the main driver of Nephrops appears to be the estimated PP anomalies.

Based on this, a further two stepwise fitting runs were designed:

- **Run 5:** Fishing (Clyde Sea F for cod and saithe, WCofS F for haddock and whiting), vulnerabilities (predator/prey), PP anomaly (≤5 spline points).
- **Run 6:** Fishing (Clyde Sea F for cod and saithe, WCofS F for haddock and whiting), vulnerabilities (predator), PP anomaly (≤5 spline points).

The best fitting model iterations from Run 5 and Run 6 are shown in Tables 23 and 24 respectively, with a functional group sum of squares break down in Table 25. The best model from Run 5 estimated 10 predator/prey vulnerabilities (Table 26) whilst the best model from Run 6 estimated four predator vulnerabilities (Table 27) and a four spline point primary production anomaly (Figure 21).

Table 23. *Clyde Sea Ecosim model iterations with the lowest AICc scores using* ***Run 5*** *hypotheses: Fishing (Clyde Sea F for cod and saithe, WCofS F for haddock and whiting), vulnerabilities (predator/prey), PP anomaly (≤5 spline points). The table includes the number of parameter estimates (K) and how these were distributed between vulnerability estimates (V's) and primary production anomaly spline points (PP).*

Model Iteration	K	V's	PP	SS	AIC	AICc	ΔAICc
Fishing and 10v	10	10	0	48.534	-269.334	-268.396	0.000
Fishing and 11v	11	11	0	47.980	-269.430	-268.278	0.118
Fishing and 8v	8	8	0	51.870	-260.245	-259.668	8.728
Fishing and 7v	7	7	0	53.825	-254.901	-254.470	13.926
Fishing and 6v	6	6	0	55.341	-251.408	-251.102	17.294

Table 24. *Clyde Sea Ecosim model iterations with the lowest AICc scores using* ***Run 6*** *hypotheses: Fishing (Clyde Sea F for cod and saithe, WCofS F for haddock and whiting), vulnerabilities (predator), PP anomaly (≤5 spline points). The table includes the number of parameter estimates (K) and how these were distributed between vulnerability estimates (V's) and primary production anomaly spline points (PP).*

Model Iteration	K	V's	PP	SS	AIC	AICc	ΔAICc
Fishing and 4v + 4pp	8	4	4	38.278	-321.932	-321.354	0.000
Fishing and 1v + 2pp	3	1	2	50.601	-275.896	-275.836	45.519
Fishing and 8v	8	8	0	48.510	-273.840	-273.263	48.092
Fishing and 6v	6	6	0	49.891	-272.455	-272.149	49.206
Fishing and 5v	5	5	0	50.447	-272.330	-272.127	49.227

Table 25. *Sum of squares (SS) breakdown showing the capacity the best models (ΔAICc = 0) from two model hypothesis to replicate observed biomass and catch trends for six functional groups in the Clyde Sea Ecopath with Ecosim (EwE) model. Runs 5 and 6 use fishing mortality drivers from the Clyde Sea data set for cod, saithe, herring and Nephrops and fishing mortality drivers from the West Coast of Scotland for haddock and whiting. Run 5 assigns vulnerabilities to specific predator/prey interactions whilst Run 6 assigns vulnerabilities to predators.*

Time series	Functional group	Sum of squares (SS)	
		Run 5	Run 6
Biomass	Cod	0.957	2.522
	Haddock	2.194	3.046
	Saithe	0.639	0.130
	Whiting	0.934	1.035
	Herring	1.248	1.505
	Nephrops	3.198	2.313
Catch	Cod	5.036	6.096
	Haddock	8.098	5.264
	Saithe	14.433	8.123
	Whiting	3.141	2.074
	Herring	5.442	3.839
	Nephrops	3.209	2.313

Pred/Prey	Sharks	Cod	Haddock	Saithe	Whiting	Nephrops
Cod	1.00E+10			1.065641	1.00E+10	
Whiting		1.357141				
Prawns and shrimp		13102.23				
Other invertebrates		1.00E+10				
Large zooplankton		1.00E+10			1	1.00E+10
Small zooplankton		1.00E+10				

Table 26. *Clyde Sea Ecosim predator/prey vulnerabilities estimated by the best fit model (ΔAICc = 0) using the* ***Run 5*** *hypothesis Fishing (Clyde Sea F for cod, saithe, herring and Nephrops, WCofS F for haddock and whiting), vulnerabilities (predator/prey), PP anomaly (≤5 spline points)).*

Pred/Prey	Cod	Saithe	Whiting	Nephrops
Rays and skates	14.39626			
Cod	14.39626	2.531709	1.091048	
Haddock	14.39626	2.531709	1.091048	
Saithe			1.091048	
Whiting	14.39626		1.091048	
Other demersals	14.39626	2.531709	1.091048	
Flatfish	14.39626	2.531709	1.091048	
Mackerel	14.39626		1.091048	
Herring	14.39626	2.531709	1.091048	
Sandeels	14.39626	2.531709	1.091048	
Other pelagic	14.39626	2.531709	1.091048	
Crabs and lobsters	14.39626		1.091048	
Nephrops	14.39626			
Prawns and shrimp	14.39626	2.531709	1.091048	
Cephalopods	14.39626	2.531709	1.091048	
Other invertebrates	14.39626		1.091048	5.113538
Large zooplankton	14.39626	2.531709	1.091048	5.113538
Small zooplankton	14.39626		1.091048	5.113538
Phytoplankton	14.39626		1.091048	

Table 27. *Clyde Sea Ecosim predator/prey vulnerabilities estimated by the best fit model (ΔAICc = 0) using the* ***Run 6*** *hypothesis Fishing (Clyde Sea F for cod, saithe, herring and Nephrops, WCofS F for haddock and whiting), vulnerabilities (predator), PP anomaly (≤5 spline points)).*

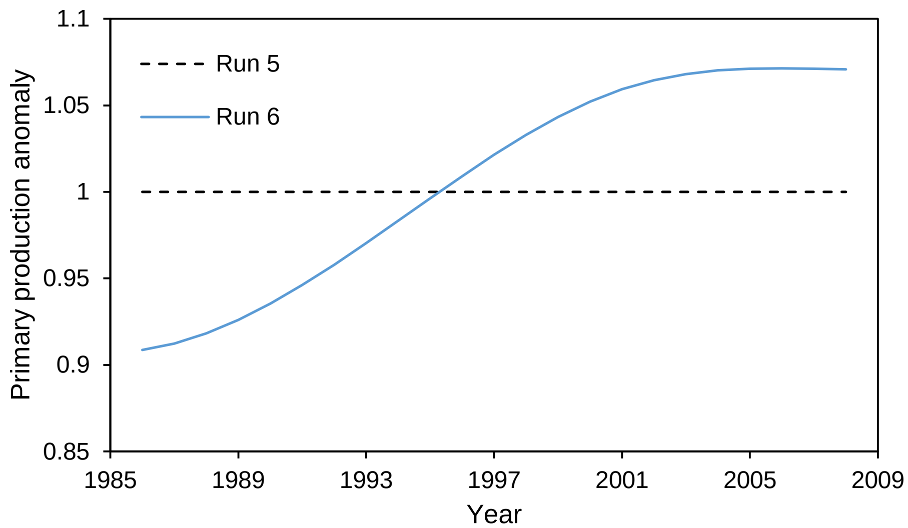


Figure 21. *Primary production (PP) anomalies estimated for the best fit models (ΔAICc = 0) from four model hypothesis (Runs 5 - 6).*

Clyde Sea Ecosim projections: 2

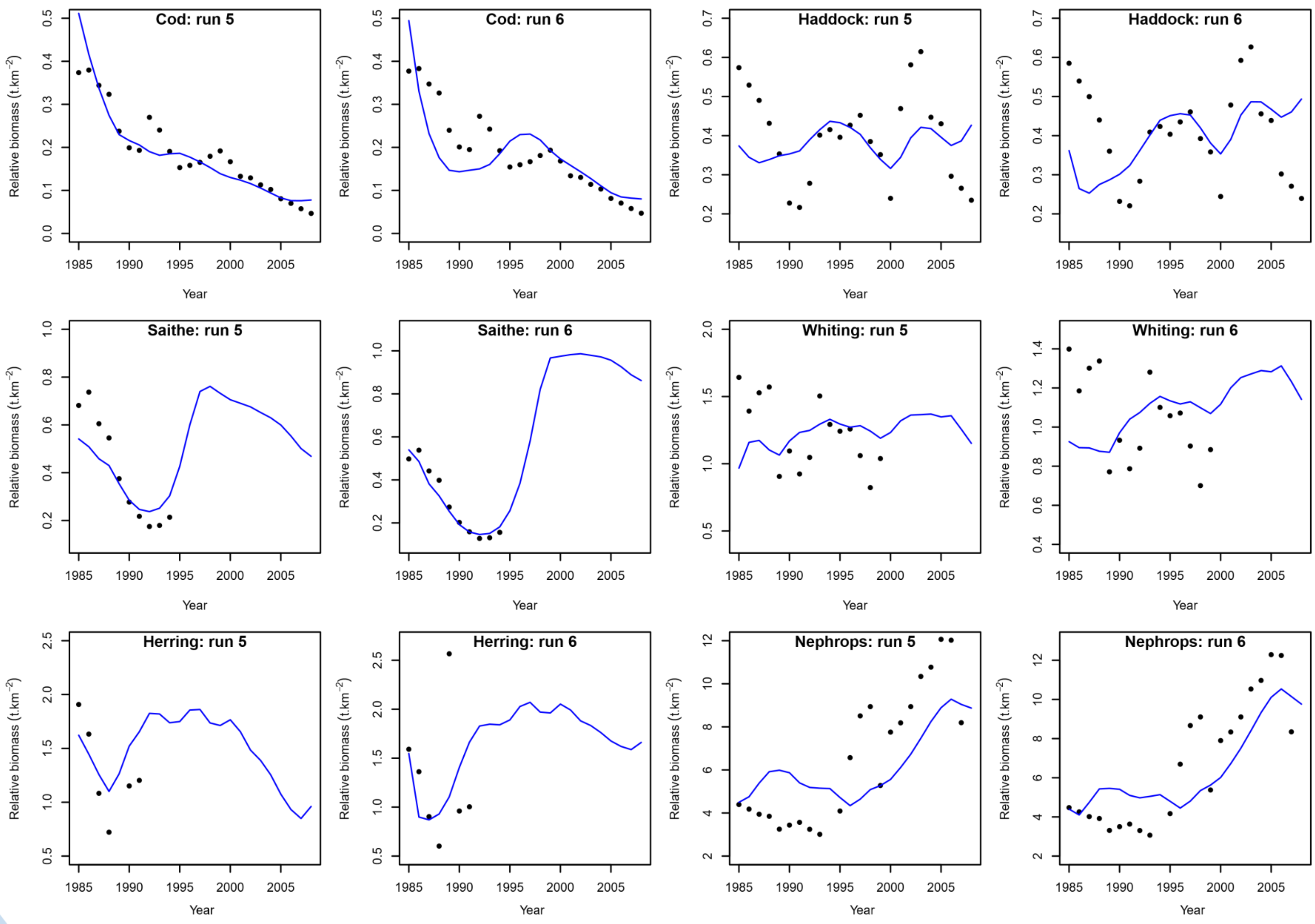


Figure 22. Observed (black dots) and predicted (blue lines) relative biomass trends for functional groups in the Clyde Sea Ecopath with Ecosim model. Model simulations were run under two hypotheses (Runs 5 and 6). Runs 5 and 6 use fishing mortality drivers from the Clyde Sea data set for cod, saithe, herring and Nephrops and fishing mortality drivers from the West Coast of Scotland for haddock and whiting. Run 5 assigns vulnerabilities to specific predator/prey interactions whilst Run 6 assigns vulnerabilities to predators.

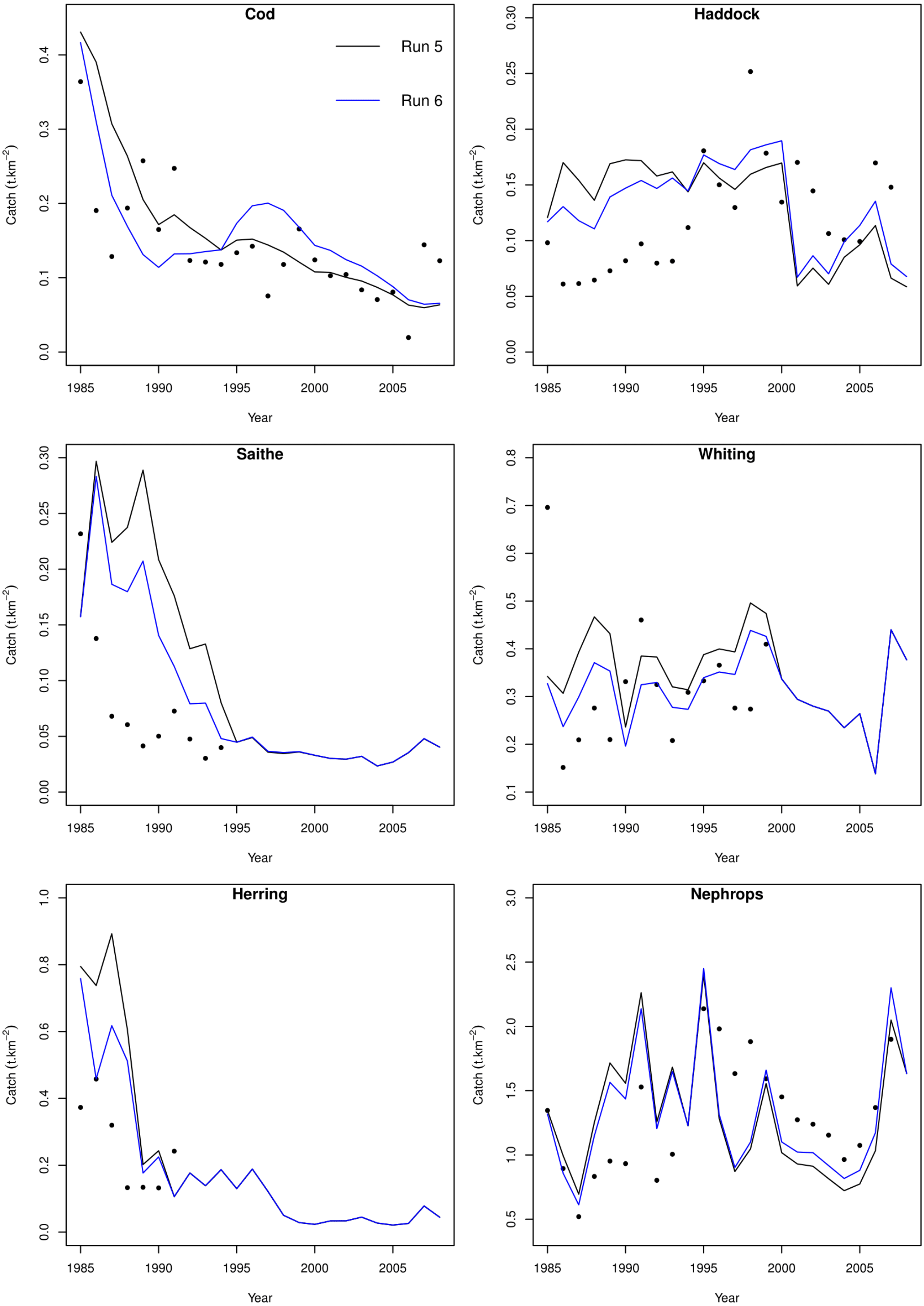


Figure 23. Observed (black dots) and predicted catch trends for functional groups in the Clyde Sea Ecopath with Ecosim model. Model simulations were run under two hypothesis (Runs 5 and 6). Runs 5 and 6 use fishing mortality drivers from the Clyde Sea data set for cod, saithe, herring and Nephrops and fishing mortality drivers from the West Coast of Scotland for haddock and whiting. Run 5 assigns vulnerabilities to specific predator/prey interactions whilst Run 6 assigns vulnerabilities to predators.

Model selection for MSP

Going forward we suggest it is preferable to use the F time series from the WCofS model (Runs 3 and 4). Both the Clyde and WCofS model take their F time series from the whole of ICES area VIa. These data are subject to regular updates as knowledge and methods progress. The exact source and date from which the F time series for the Clyde were collected is unknown, whereas the WCofS F is regularly updated based on ICES advice.

For the MSP framework the notion of time is taken away, instead the EwE model serves to provide a static baseline from which users can implement drivers to investigate their potential impact on the ecosystem. Therefore, temporal drivers such as time series, fishing effort and primary production anomalies cannot be included in the final model. This means the models suggested by our stepwise fitting iterations with PP anomalies cannot be used for the purpose of this project. Instead, only models with vulnerability estimates can be put forward, as the vulnerabilities remain in the steady state model to allow for mixed top-down and bottom-up control realistic to the ecology of the system and likely to dictate how the system reacts to change. The best models from Runs 3 and 4 without PP anomalies are presented in Tables 28 and 29 respectively. The sum of squares breakdown is shown in Table 30.

Table 28. *Clyde Sea Ecosim model iterations from the* ***Run 3*** *hypothesis': Fishing (WCofS fishing mortality), vulnerabilities (predator/prey), PP anomaly (≤5 spline points). The table includes the number of parameter estimates (K) and how these were distributed between vulnerability estimates (V's) and primary production anomaly spline points (PP). The models presented are the top 5 iterations (lowest AICc) which do not include an estimated PP anomaly.*

Model Iteration	K	V's	PP	SS	AIC	AICc	ΔAICc
Fishing and 5v	5	5	0	56.200	-250.405	-250.202	0.000
Fishing and 6v	6	6	0	56.084	-248.700	-248.394	1.809
Fishing and 7v	7	7	0	56.084	-246.555	-246.124	4.078
Fishing and 8v	8	8	0	56.139	-244.190	-243.613	6.589
Fishing and 4v	4	4	0	59.096	-242.307	-242.186	8.016

Table 29. *Clyde Sea Ecosim model iterations from the* ***Run 4*** *hypothesis': Fishing (WCofS fishing mortality), vulnerabilities (predator/prey), PP anomaly (≤5 spline points). The table includes the number of parameter estimates (K) and how these were distributed between vulnerability estimates (V's) and primary production anomaly spline points (PP). The models presented are the top 5 iterations (lowest AICc) which do not include an estimated PP anomaly.*

Model Iteration	K	V's	PP	SS	AIC	AICc	ΔAICc
Fishing and 6v	6	6	0	49.467	-274.188	-273.882	0.000
Fishing and 5v	5	5	0	50.165	-273.468	-273.264	0.617
Fishing and 7v	7	7	0	49.481	-271.983	-271.553	2.329
Fishing and 8v	8	8	0	49.291	-270.598	-270.020	3.861
Fishing and 9v	9	9	0	49.303	-268.358	-267.612	6.270

Table 30. *Sum of squares (SS) breakdown showing the capacity the best models (ΔAICc = 0) from two model hypothesis (excluding those with PP anomalies) to replicate observed biomass and catch trends for six functional groups in the Clyde Sea Ecopath with Ecosim (EwE) model. Runs 3 and 4 use fishing mortality drivers from the West Coast of Scotland. Run 3 assigns vulnerabilities to specific predator/prey interactions whilst Run 4 assigns vulnerabilities to predators.*

Time series	Functional group	Sum of squares	
		Run 3	Run 4
Biomass	Cod	6.274	5.757
	Haddock	1.728	1.345
	Saithe	3.814	2.392
	Whiting	0.746	0.425
	Herring	1.351	1.344
	Nephrops	3.129	2.367
Catch	Cod	11.681	10.902
	Haddock	7.401	8.155
	Saithe	9.826	6.596
	Whiting	2.850	2.719
	Herring	4.262	4.021
	Nephrops	3.133	3.431

MSP models: Vulnerabilities

The predator prey vulnerabilities for the best fitting model in Run 3 (excluding models with PP anomalies) includes 5 estimated trophic interactions (Table 31). The best fitting model from Run 4 (excluding those with PP anomalies) also estimates five vulnerabilities, however these estimates cover the entire diets of five predators (Table 32).

*Table 31. Clyde Sea Ecosim predator/prey vulnerabilities estimated by the best fitting model without a PP anomaly from the **Run 3** hypothesis: Fishing (WCofS F), vulnerabilities (predator/prey)).*

Pred/Prey	Haddock	Saithe	Whiting	Nephrops
Cod		1.00E+10		
Haddock		1		
Large zooplankton	2.1171		1	1.32E+06

*Table 32. Clyde Sea Ecosim predator/prey vulnerabilities estimated by the best fitting model without a PP anomaly from the **Run 4** hypothesis: Fishing (WCofS F), vulnerabilities (predator/prey)).*

Pred/Prey	Sharks	Cod	Haddock	Saithe	Whiting	Nephrops
Sharks	1.00E+10					
Rays and skates	1.00E+10	1				
Cod	1.00E+10	1		1	1.0332	
Haddock	1.00E+10	1	2.0372	1	1.0332	
Saithe	1.00E+10				1.0332	
Whiting	1.00E+10	1			1.0332	
Other demersals	1.00E+10	1	2.0372	1	1.0332	
Flatfish	1.00E+10	1		1	1.0332	
Mackerel	1.00E+10	1			1.0332	
Herring	1.00E+10	1	2.0372	1	1.0332	
Sandeels	1.00E+10	1	2.0372	1	1.0332	
Other pelagic	1.00E+10	1	2.0372	1	1.0332	
Crabs and lobsters	1.00E+10	1			1.0332	
Nephrops		1				
Prawns and shrimp	1.00E+10	1	2.0372	1	1.0332	
Cephalopods	1.00E+10	1		1	1.0332	
Other invertebrates	1.00E+10	1	2.0372		1.0332	43.4221
Large zooplankton	1.00E+10	1	2.0372	1	1.0332	43.4221
Small zooplankton		1	2.0372		1.0332	43.4221
Phytoplankton		1	2.0372		1.0332	

The model iteration used for the MSP gameplay model was taken from Run 4 (WCofS F and Predator/Prey vulnerabilities). The iteration includes fishing and 6 vulnerabilities and provided the best fit (SS and AICc) when compared to other iterations suitable for MSP gameplay.

Clyde Sea Ecosim projections: 3

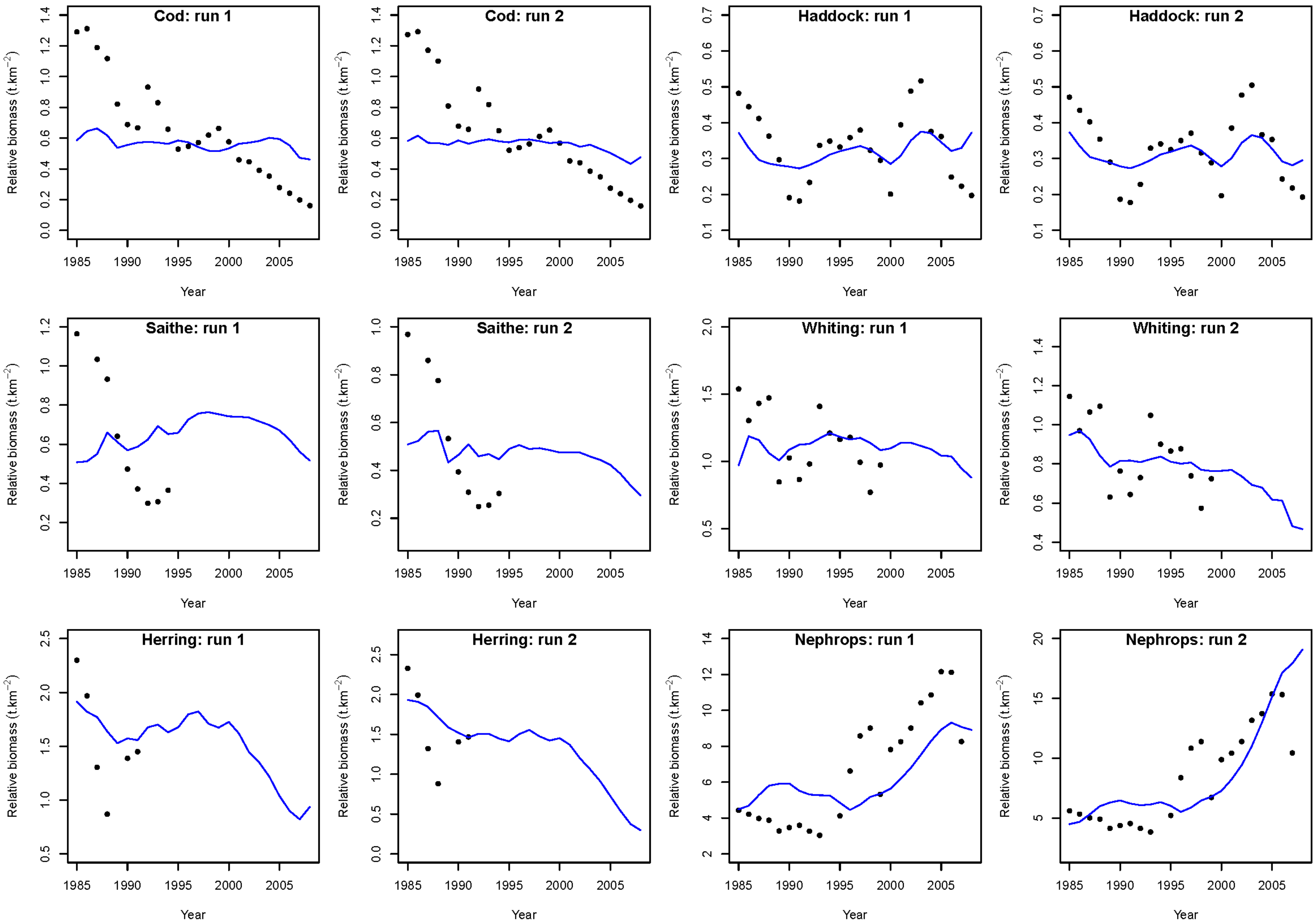


Figure 24. Observed (black dots) and predicted (blue lines) relative biomass trends for functional groups in the Clyde Sea Ecopath with Ecosim model. Model simulations were run under two hypotheses (Runs 3 and 4) and the iterations selected were those with the lowest AICc values without estimated PP anomalies. Runs 3 and 4 use fishing mortality drivers from West Coast of Scotland. Run 3 assigns vulnerabilities to specific predator/prey interactions whilst Run 4 assigns vulnerabilities to predators.

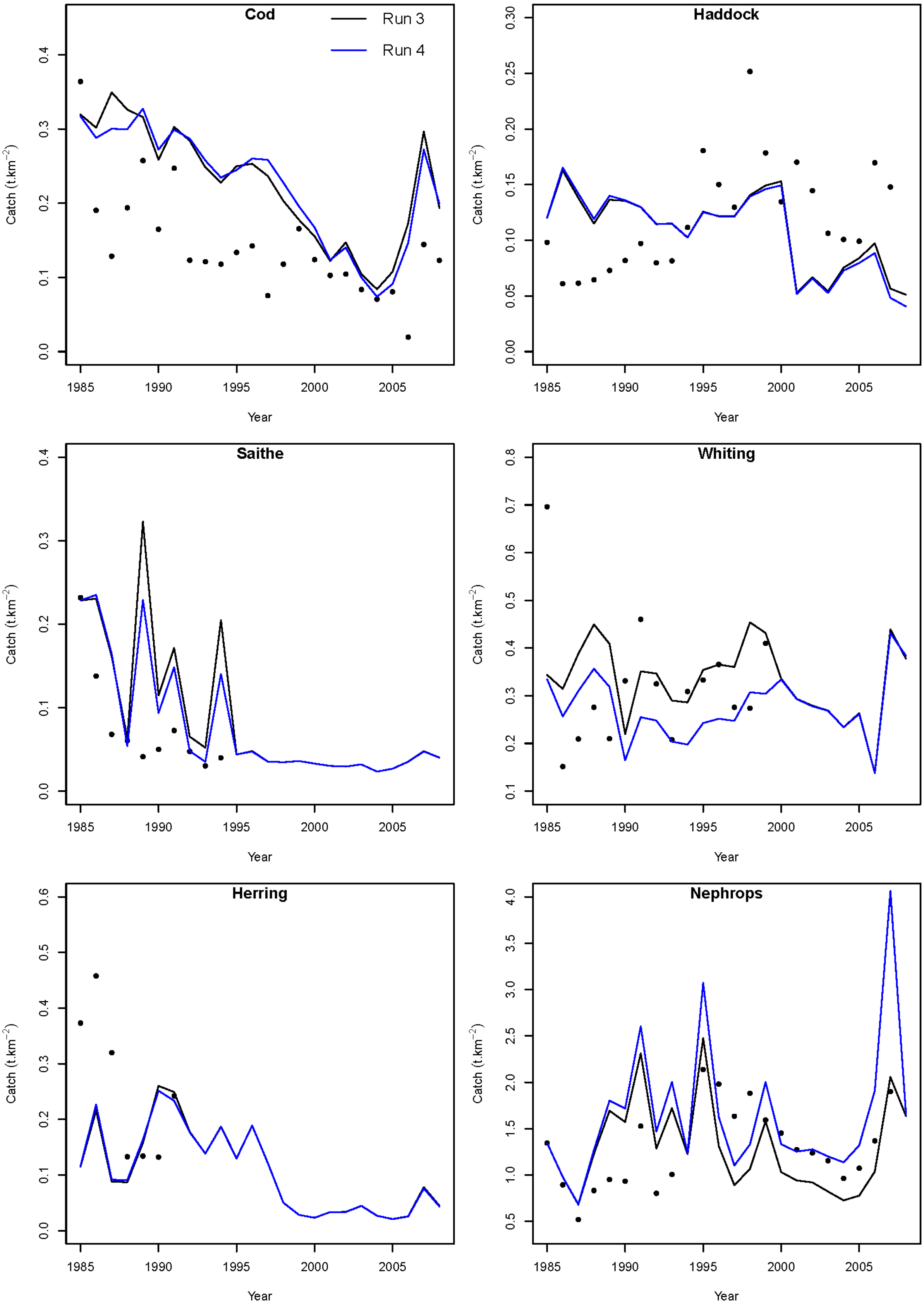


Figure 25. Observed (black dots) and predicted catch trends for functional groups in the Clyde Sea Ecopath with Ecosim model. Model simulations were run under two hypotheses (Runs 3 and 4) and the iterations selected were those with the lowest AICc values without estimated PP anomalies. Runs 3 and 4 use fishing mortality drivers from West Coast of Scotland. Run 3 assigns vulnerabilities to specific predator/prey interactions whilst Run 4 assigns vulnerabilities to predators.

Ecospace

Original Clyde Sea map and habitat distribution

The original Clyde Sea model was incredible coarse and not georeferenced (Figure 26). Localised impacts would be difficult to interpret at this 7.15 km^2 resolution and one cell wide water paths may have disrupted inhibited the realistic movement of species. The map was also over complicated in terms of the number of habitat designations.

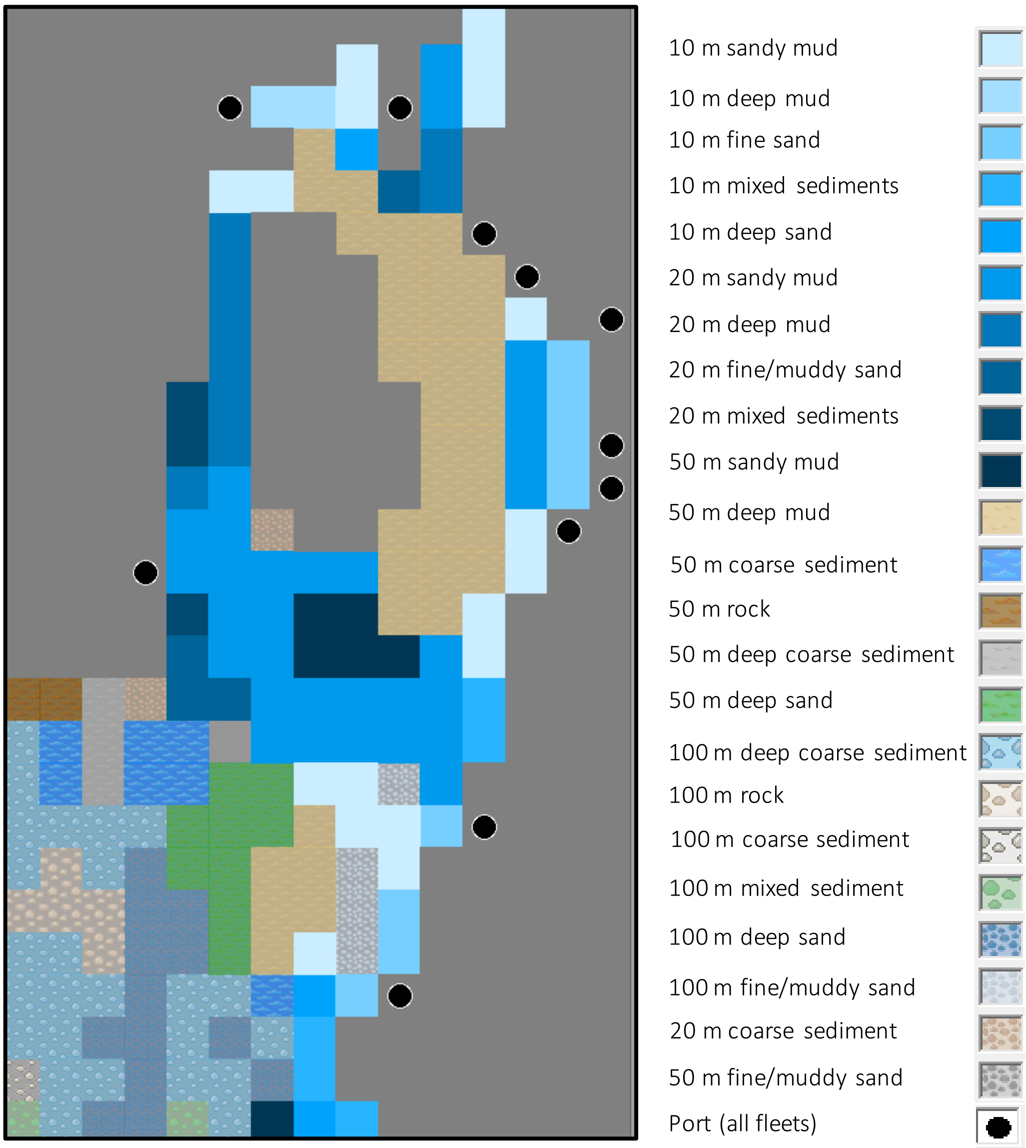


Figure 26. Ecospace map of the original Clyde Sea model including 23 habitats and designated ports.

Habitat foraging usage

Habitat preference in the original Clyde Sea model was determined based on habitat foraging usage (Table 33).

Table 33. Habitat foraging usage in the original Clyde Sea Ecospace model.

Functional group	All	10m sandy mud	10m deep mud	10m fine sand	10m mixed sediments	10m deep sand	20m sandy mud	20m deep mud	20m fine/ muddy sand	20m mixed sediments	50m sandy mud	50m deep mud	50m coarse sediment
Seals	0	1	1	1	1	1	1	1	1	1	1	1	1
Cetaceans	0	1	1	1	1	1	1	1	1	1	1	1	1
Birds	0	1	1	1	1	1	1	1	1	1	1	1	1
Sharks	1	0	0	0	0	0	0	0	0	0	0	0	0
Rays and skates	0	1	1	1	1	1	1	1	1	1	1	1	1
Cod	0	1	1	1	1	1	1	1	1	1	1	1	1
Haddock	0	0	0	0	0	0	0	0	1	1	0	0	1
Saithe	0	1	1	1	1	1	1	1	1	1	1	1	1
Whiting	0	0	0	0	0	0	0	0	0	0	1	1	1
Other demersals	0	1	1	1	1	1	1	1	1	1	1	1	1
Flatfish	0	0	0	1	1	0	0	0	1	1	0	0	1
Mackerel	1	0	0	0	0	0	0	0	0	0	0	0	0
Herring	1	0	0	0	0	0	0	0	0	0	0	0	0
Sandeels	0	0	0	1	1	1	0	0	0	1	0	0	1
Other pelagic	1	0	0	0	0	0	0	0	0	0	0	0	0
Crabs and lobsters	0	0	0	0	1	1	1	0	0	1	1	0	1
Nephrops	0	1	1	0	1	0	1	1	1	0	1	1	0
Prawns and shrimp	1	0	0	0	0	0	0	0	0	0	0	0	0
Cephalopods	0	1	1	1	1	1	1	1	1	1	1	1	1
Other invertebrates	0	1	1	1	1	1	1	1	1	1	1	1	1
Large zooplankton	1	0	0	0	0	0	0	0	0	0	0	0	0
Small zooplankton	1	0	0	0	0	0	0	0	0	0	0	0	0
Phytoplankton	1	0	0	0	0	0	0	0	0	0	0	0	0
Detritus	1	0	0	0	0	0	0	0	0	0	0	0	0

Functional group	50m rock	50m deep coarse sediment	50m deep sand	100m deep coarse sediment	100m rock	100m coarse sediment	100m mixed sediments	100m deep sand	100m fine/ muddy sand	20m coarse sediment	50m fine/ muddy sand	Artificial substrate
Seals	1	1	1	0	0	0	0	0	0	1	1	0.1
Cetaceans	1	1	1	1	1	1	1	1	1	1	1	0.2
Birds	1	1	1	1	1	1	1	1	1	1	1	0.2
Sharks	0	0	0	0	0	0	0	0	0	0	0	0
Rays and skates	0	1	1	1	0	1	1	1	1	1	1	0
Cod	1	1	1	1	1	1	1	1	1	1	1	0.2
Haddock	1	1	1	1	1	1	1	1	0	1	0	0.2
Saithe	1	1	1	1	1	1	1	1	1	1	1	0.2
Whiting	1	1	1	1	1	1	1	1	1	0	1	0.2
Other demersals	1	1	1	1	1	1	1	1	0	1	0	0.2
Flatfish	0	1	1	1	0	1	1	1	1	1	1	0
Sandeels	0	1	1	1	0	1	1	1	0	1	0	0
Crabs and lobsters	1	1	1	1	1	1	1	1	0	1	0	0.3
Nephrops	0	0	0	0	0	0	1	1	1	0	1	0
Cephalopods	0	1	1	1	0	1	1	1	1	1	1	0
Other invertebrates	1	1	1	1	1	1	1	1	1	1	1	0.2

Fleet habitat usage

Assigning fleet habitat usage determines where fishing fleets will and will not operate (Table 34).

Table 34. *Fleet habitat usage in the Clyde Sea Ecospace model.*

Fleet habitat usage	10m sandy mud	10m deep mud	10m fine sand	10m mixed sediments	10m deep sand	20m sandy mud	20m deep mud	20m fine/ muddy sand	20m mixed sediments	50m sandy mud	50m deep mud	50m coarse sediment
Demersal trawl	0	0	0	0	0	0	0	0	0	1	1	1
Dredge	0	0	0	0	0	1	1	1	1	1	1	1
Hand collecting	1	1	1	1	1	1	1	1	1	0	0	0
Line fishing	1	1	1	1	1	1	1	1	1	1	1	1
Nephrops fleet	1	1	0	1	0	1	1	1	1	1	1	0
Pelagic trawl	0	0	0	0	0	1	1	1	1	1	1	1
Pots and creels	1	1	1	1	1	1	1	1	1	0	0	0
Seine	0	0	0	0	0	1	1	1	1	1	1	1

Fleet habitat usage	50m rock	50m deep coarse sediment	50m deep sand	100m deep coarse sediment	100m rock	100m coarse sediment	100m mixed sediments	100m deep sand	100m fine/ muddy sand	20m coarse sediment	50m fine/ muddy sand
Demersal trawl	1	1	1	1	1	1	1	1	1	0	1
Dredge	1	1	1	1	1	1	1	1	1	1	1
Hand collecting	0	0	0	0	0	0	0	0	0	1	0
Line fishing	1	1	1	0	0	0	0	0	0	1	1
Nephrops fleet	0	0	0	0	0	0	1	0	1	0	1
Pelagic trawl	1	1	1	1	1	1	1	1	1	1	1
Pots and creels	0	0	0	0	0	0	0	0	0	1	0
Seine	1	1	1	1	1	1	1	1	1	1	1

New Clyde Ecospace Map

To fulfil the needs of the MSP gameplay routine, a new Ecospace model was developed with higher resolution (1.5 km^2) and fewer habitat designations (Figure 27). Habitats were grouped into five categories using Emodnet habitat data.

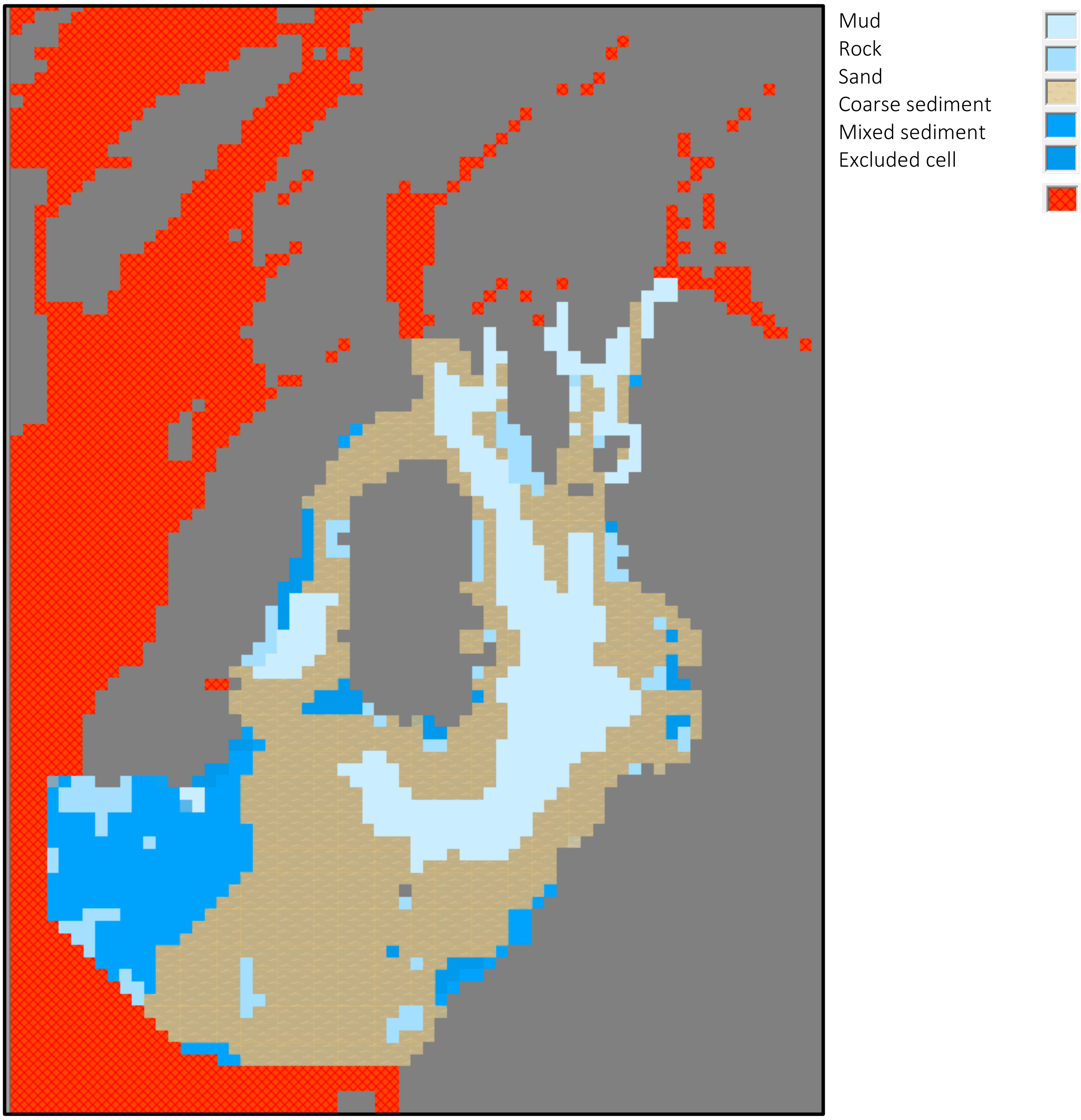


Figure 26. Ecospace map of the Clyde Sea developed for the MSP gameplay tool.

MSP habitat foraging and fleet habitat usage

Habitat foraging usage data was reassigned by grouping the old habitat categories together using the new habitat designations (Table 35). For example, if a total of four old habitats were amalgamated into a single new group (i.e. sand), and a certain species appeared in only 3/4 of those groups, then that species preference for the grouped habitat would be 0.75 (75%). Fleet habitat usage was reassigned based on whether they can (1) or can't (0) fish in certain habitats (Table 36).

Table 35. Habitat foraging usage in the updated MSP Clyde Sea Ecospace model.

Functional group	All	Mud	Rock	Sand	Coarse sediment	Mixed sediment	Artificial substrate
Seals	0	1	0.5	0.7	0.6	0.7	0.1
Cetaceans	0	1	1	1	1	1	0.2
Birds	0	1	1	1	1	1	0.2
Sharks	1	0	0	0	0	0	0
Rays and skates	0	1	0	1	1	1	0
Cod	0	1	1	1	1	1	0.2
Haddock	0	0.0	1	0.4	1	0.7	0.2
Saithe	0	1	1	1	1	1	0.2
Whiting	0	0.3	1	0.6	0.8	0.3	0.2
Other demersals	0	1	1	0.7	1	1	0.2
Flatfish	1	0	0	0	0	0	0
Mackerel	1	0	0	0	0	0	0
Herring	1	0	0	0	0	0	0
Sandeels	0	0	0	0.6	1	1	0
Other pelagic	1	0	0	0	0	0	0
Crabs and lobsters	0	0.3	1	0.4	1	1	0.3
Nephrops	0	1	0	0.6	0	0.7	0
Prawns and shrimp	1	0	0	0	0	0	0
Cephalopods	0	1	0	1	1	1	0
Other invertebrates	0	1	1	1	1	1	0.2
Large zooplankton	1	0	0	0	0	0	0
Small zooplankton	1	0	0	0	0	0	0
Phytoplankton	1	0	0	0	0	0	0
Detritus	1	0	0	0	0	0	0

Table 36. Fleet habitat usage in the updated MSP Clyde Sea Ecospace model.

Fleet habitat usage	Mud	Rock	Sand	Coarse sediment	Mixed sediment	Artificial substrate
Demersal trawl	1	0	1	1	1	1
Scallop fleet	1	0	1	1	1	1
Nephrops fleet	1	0	1	1	1	1
Pots and creels	1	1	1	1	1	1
Seine	1	1	1	1	1	1

MSP functional group dispersal

Dispersal rates (Mi, km/yr) of functional groups were calculated from individual swimming speeds (Si, km/yr) (Table 37):

Mi = Si/πL (L being grid length in km (1.5 km)).

Individual swimming speeds were taken from the WCofS model, as was data for functional group behaviour in bad habitat.

Table 37. Functional group dispersal rates in the Clyde Sea Ecospace model.

Functional group	Base dispersal rate	Rel. dispersal in bad habitat	Rel. vulnerability to predation in bad habitat	Rel. feed rate in bad hab.
Seals	881.611	5	2	0.5
Cetaceans	1286.900	5	2	0.5
Birds	2412.980	5	2	0.5
Sharks	136.113	5	2	0.5
Rays and skates	85.680	5	2	0.5
Cod	155.511	5	2	0.5
Haddock	227.635	5	2	0.5
Saithe	519.690	5	2	0.5
Whiting	140.936	5	2	0.5
Other demersals	176.797	5	2	0.5
Flatfish	168.300	5	2	0.5
Mackerel	435.597	5	2	0.5
Herring	86.643	5	2	0.5
Sandeels	75.707	5	2	0.5
Other pelagic	168.564	5	2	0.5
Crabs and lobsters	9.030	5	10	0.1
Nephrops	227.687	1	10	0.1
Prawns and shrimp	20.797	5	2	0.5
Cephalopods	79.220	5	2	0.5
Other invertebrates	42.462	1	10	0.1
Large zooplankton	1700.000	5	2	0.5
Small zooplankton	1700.000	5	2	0.5
Phytoplankton	1700.000	5	2	0.5
Detritus	56.667	5	2	0.5

Depth

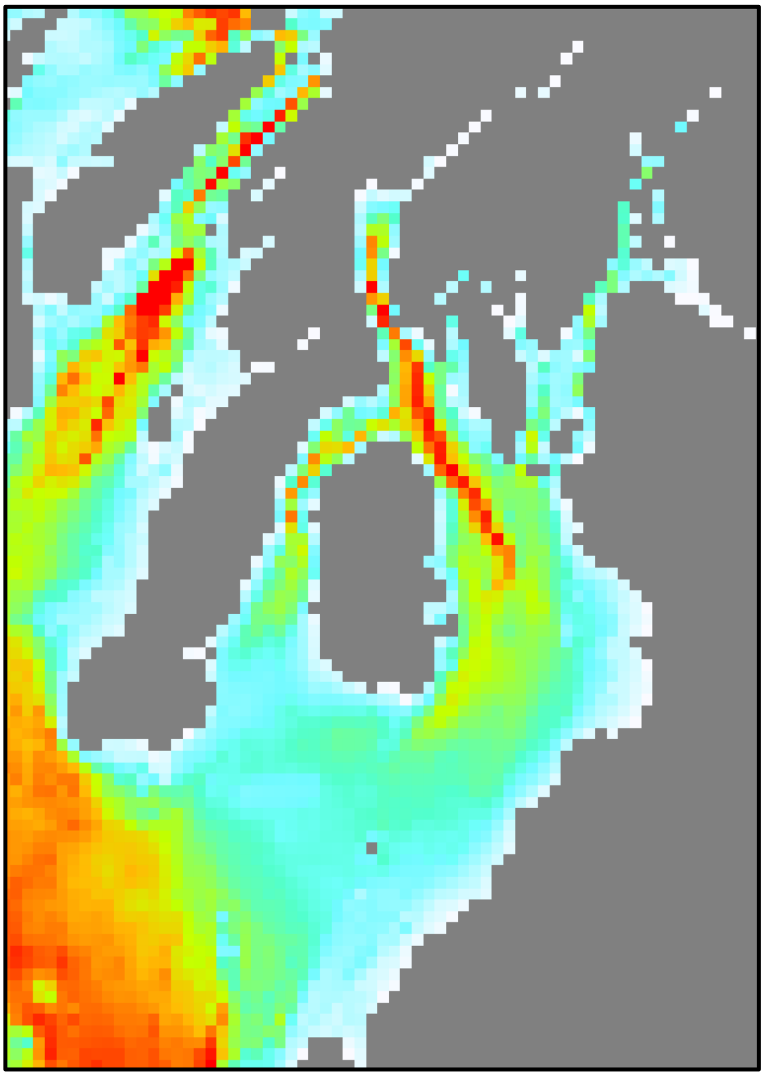


Figure 27. Depth within the Clyde Sea Ecospace model.

Depth data was attributed to the Ecospace map to be used as a driver of species habitat preference (Figure 27). Depth functional responses were assigned to 13 functional groups using minimum, maximum and optimum preferences taken from AquaMaps (http://www.aquamaps.org) (Table 38). Functional responses were assigned in the form of Gaussian response functions (Figure 28).

Table 38. Depth functional response parameters

Functional group	Min. depth	Max. depth	Optimum depth	SD right	SD left
Seals	0	500	25.5	5	180
Cetaceans	0	2000	30	14	750
Sharks	10.29	941	185.5	45	280
Rays and skates	35.56	625.3	162.56	35	160
Cod	0	600	200	40	150
Haddock	10	450	105	30	120
Saithe	37	364	131	25	50
Whiting	10	200	65	20	40
Flatfish	16.85	40.1	111.15	30	150
Mackerel	0	1000	200	30	300
Herring	0	364	100	30	75
Sandeels	1.75	61.25	34.875	9	17
Crabs and lobsters	2.5	150	31.5	7	40

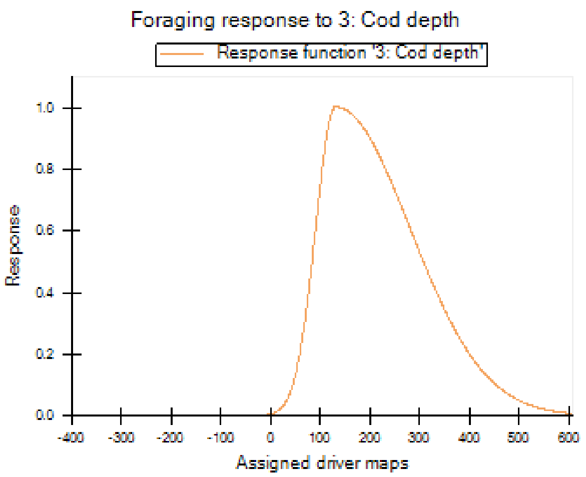


Figure 28. Gaussian functional depth response of Cod in the Clyde Sea Ecospace model.

Ecospace Results

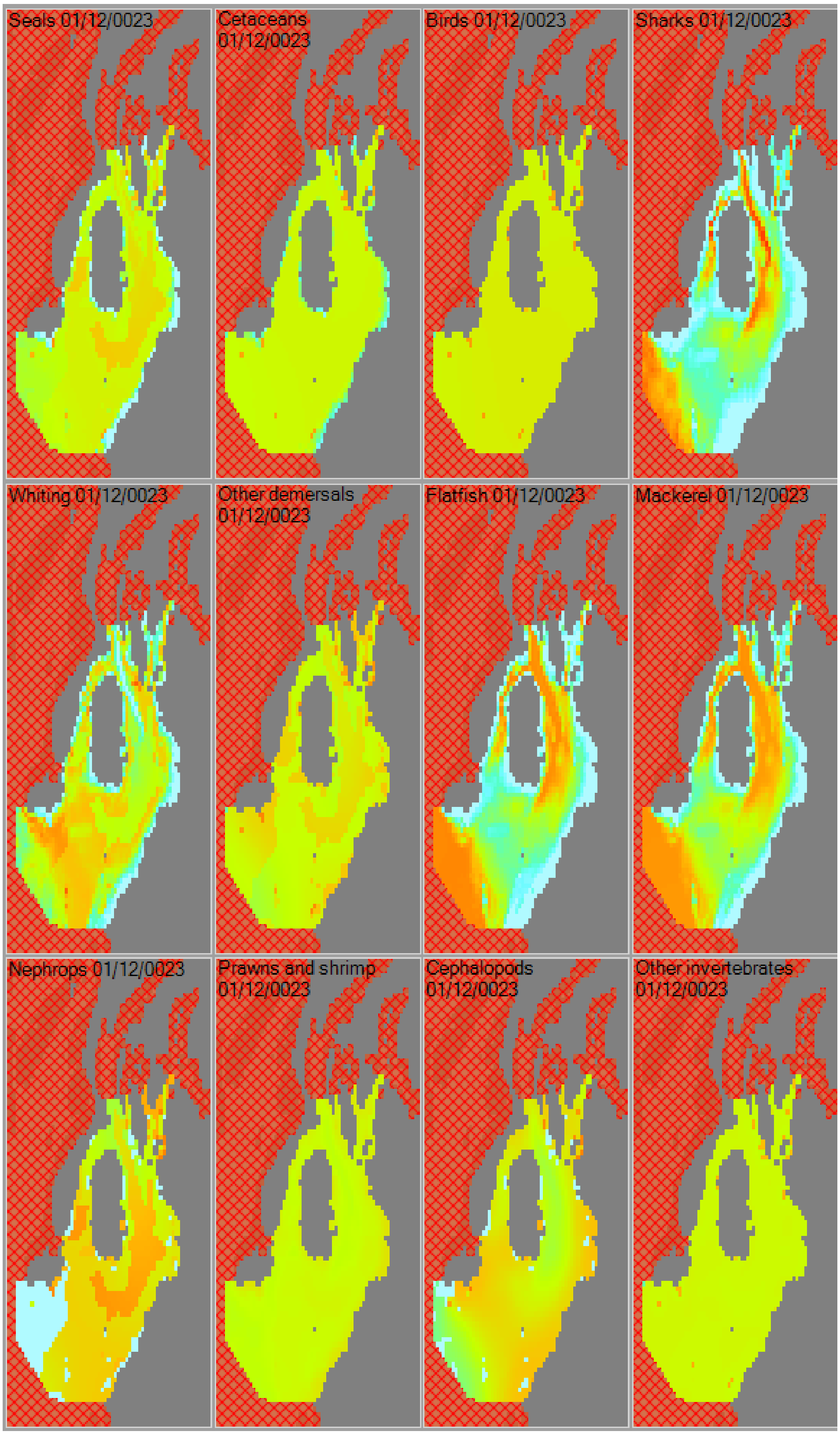


Figure 29. Relative biomass of functional groups in the Clyde Sea Ecospace model after 24 years of run time.

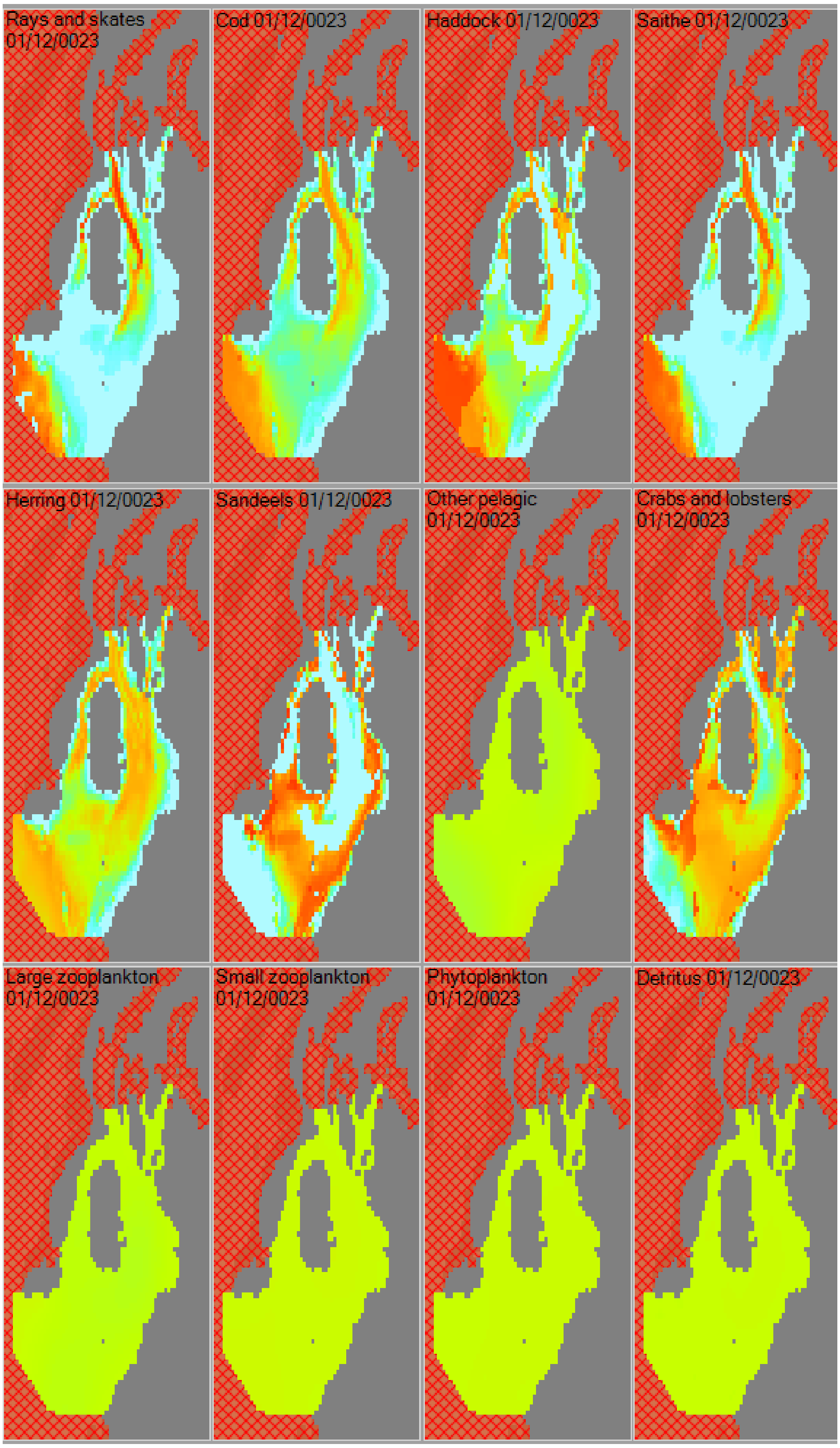


Figure 29. Continued.

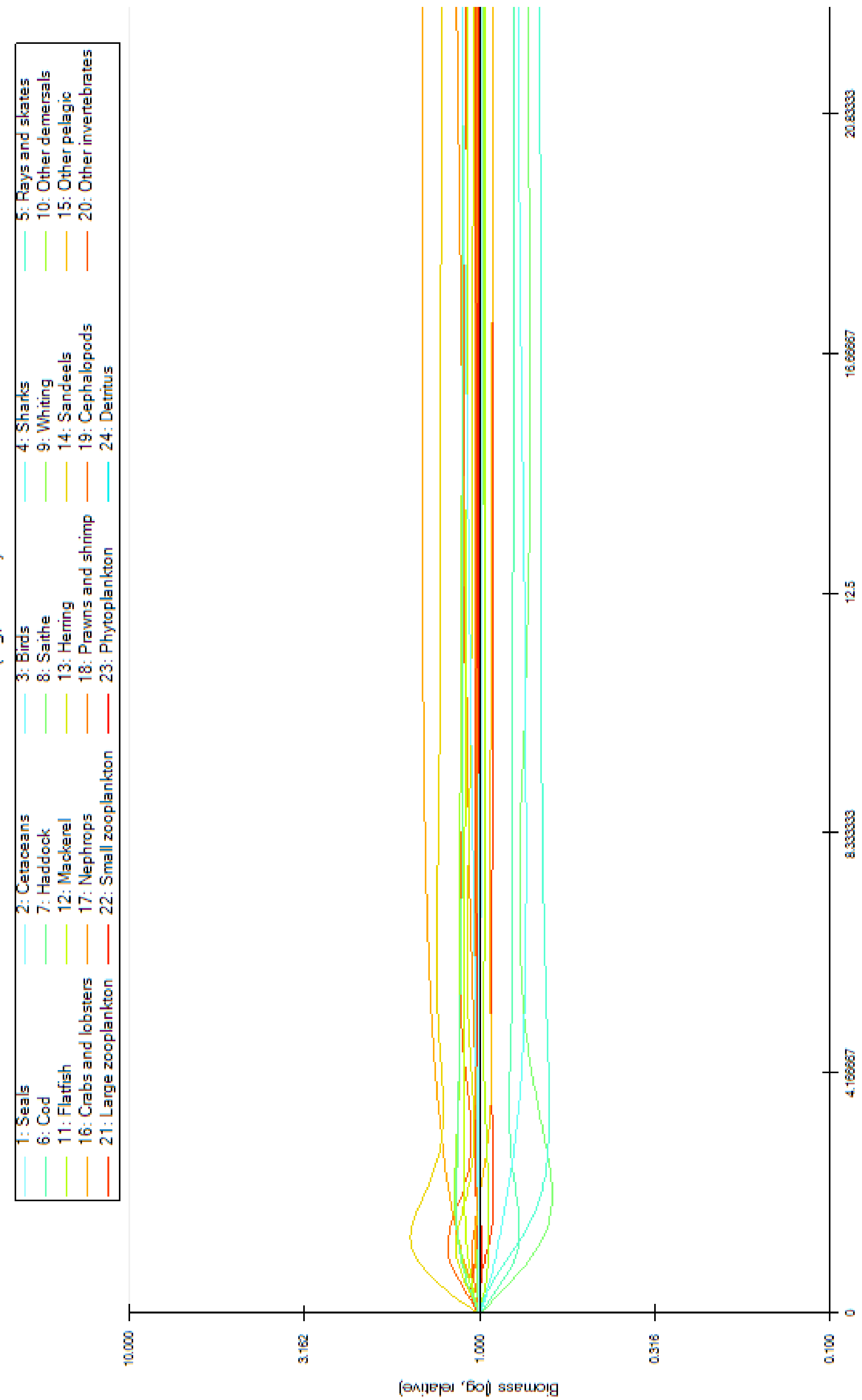


Figure 30. Relative biomass of functional groups in the Clyde Sea Ecospace model, showing stability after roughly 10 years.

MPAs and Artificial Habitat

For every fishing fleet that is separately managed in the MSP game, the Ecospace scenario must contain a dedicated MPA where that fleet is not allowed to fish. Therefore, five MPAs were generated, each excluding of the five fishing fleets.

An artificial habitat layer was created. Through habitat affinity this habitat impacts the foraging capacity model of benefitting functional groups.

MPA impacts

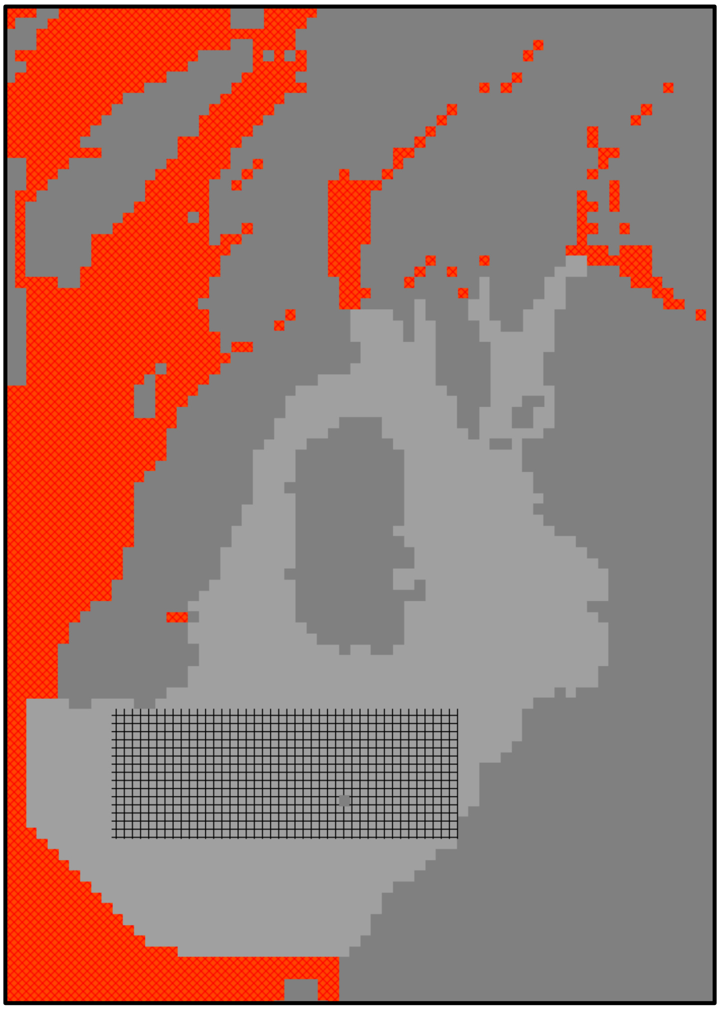


Figure 31. *MPA region (cross stitch area) in the Clyde Ecospace model*

To test the impact of the each MPA, a designated MPA region was assigned to the south of the Clyde model area. MPAs were turned on one at a time and the Ecospace model was run for 24 years (Figure 31). The biomass and catch of each functional group, as well as total catch per fleet, were recorded at the end of each run and compared to data from the MPA region when no MPAs were assigned (Figure 32).

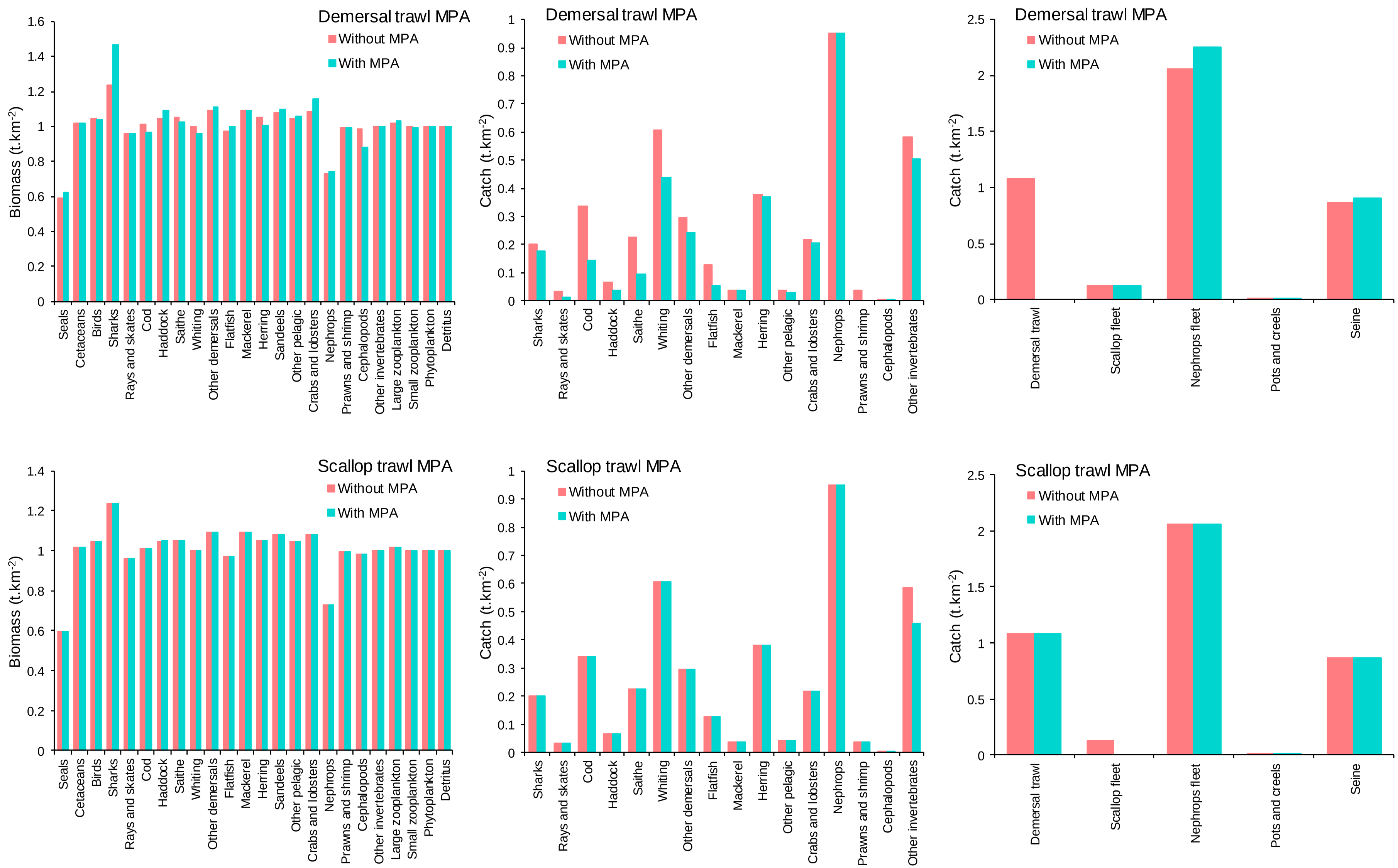


Figure 32. *Comparison of biomass and catch (t.km^{-2}) estimates when MPAs are and are not assigned to a region of the Clyde Sea Ecospace model. MPAs only exclude a single fleet. The five MPAs tested each prevent their designated fleet from fishing within the MPA region.*

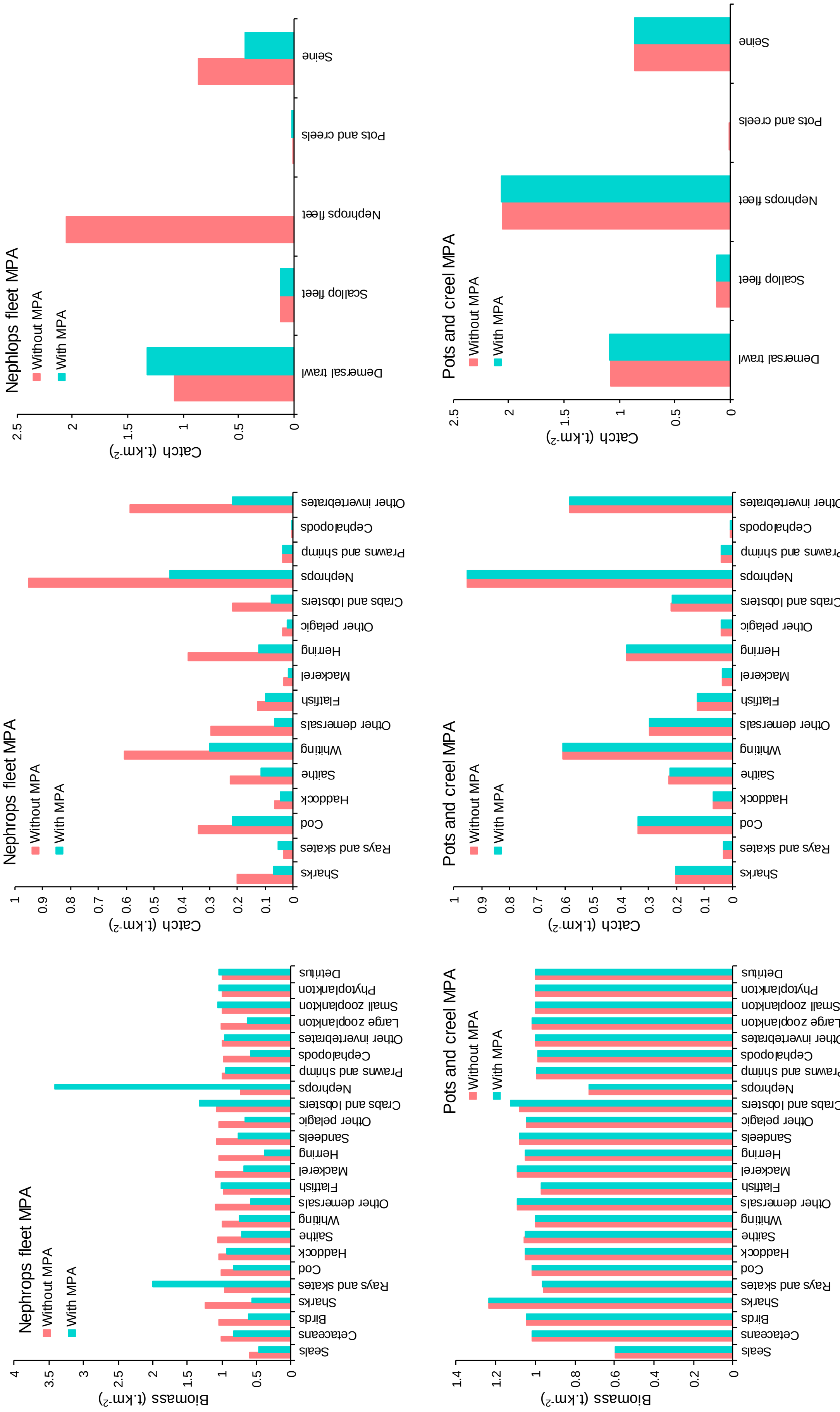


Figure 32. Continued

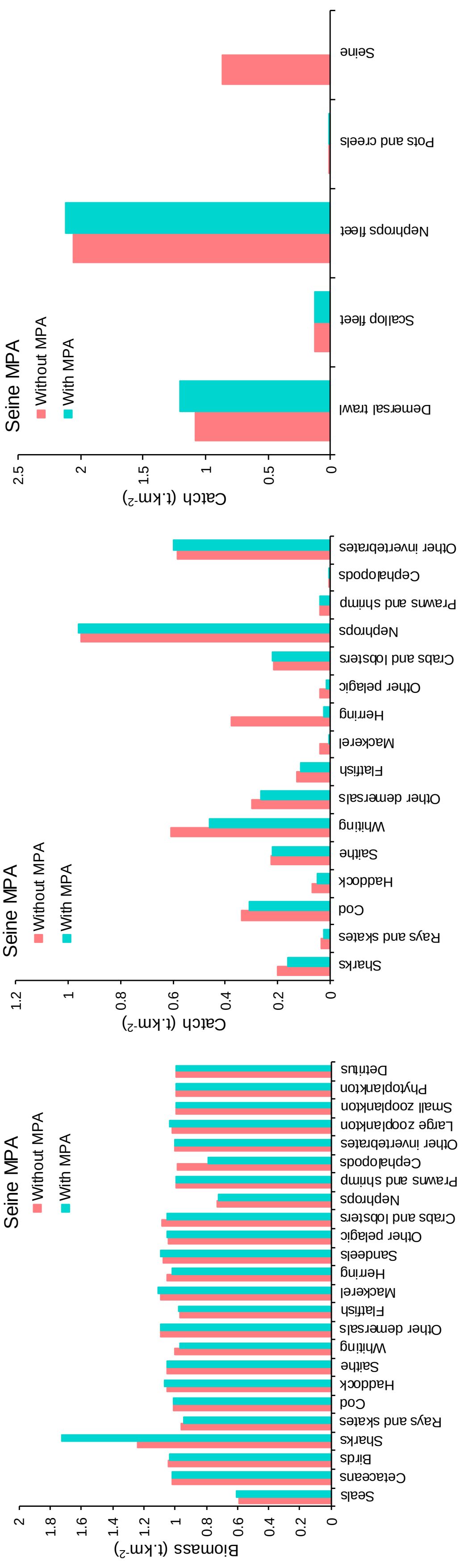


Figure 32. Continued

Environmental drivers and functional responses

For MSP gameplay the Ecospace scenario must include three environmental driver layers: 'Noise', 'Surface disturbance', and 'Bottom disturbance'. Through functional responses, these drivers impact the foraging capacity of all functional groups sensitive to these drivers with ecologically realistic response.

Two different types of impact were created: low and high (Figure 33).

The functional responses were assigned in the following fashion:

- Noise:
  - Low impact: Seals
  - High impact: Cetaceans
  - Low impact: Seabirds
- Surface disturbance:
  - Low impact: Seals
  - Low impact: Cetaceans
- Bottom disturbance:
  - High impact: Crabs and lobsters
  - High impact: Other invertebrates

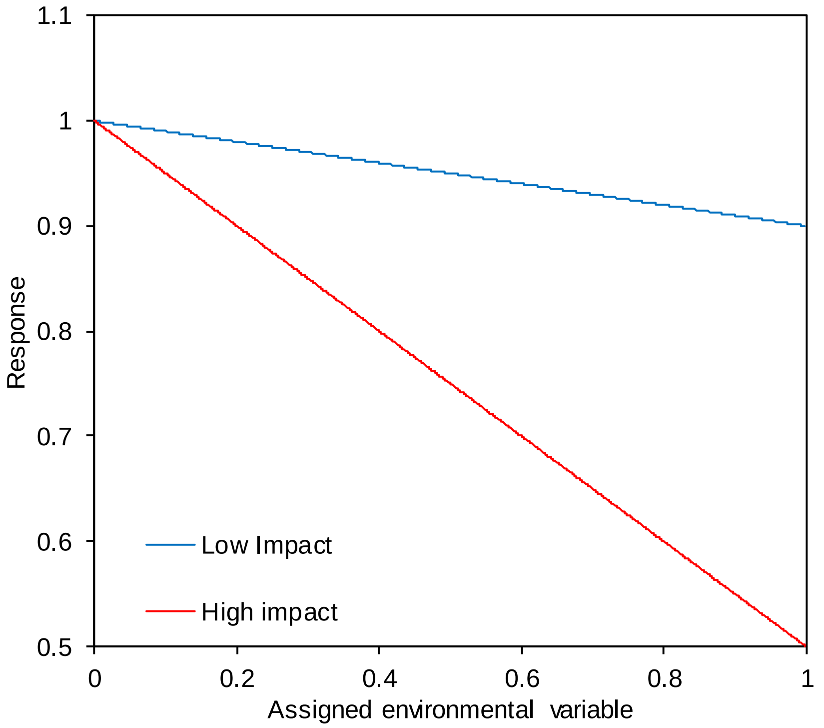


Figure 33. Functional responses attributed to certain functional groups to elicit an ecological response to noise, surface disturbance and bottom disturbance.

Testing the impacts of pressures

The general ecological impact of noise, surface, disturbance and bottom disturbance, individually and combined, were tested on the Clyde Sea Ecospace model by sub-setting a rectangular region towards the south of the Clyde as a 'pressure testing area' (Figure 34). The impact of the pressures on the biomass of functional groups within this region was tested at increasing intensities (Tables 39-41). A region of artificial substrate was also placed within the pressure region (Figure 35) and the biomass of functional groups within the region was compared with and without the artificial substrate (Table 42). We then investigated the impact of pairing the pressures with artificial substrate and compared their impact on functional groups biomasses as individual and combined pressures (Figures 36 -38).

Table 39. Functional group relative biomass changes with increasing strengths of noise pressure in the Clyde Sea Ecospace model.

Functional Group	No noise	P.0.2	P.0.4	P.0.6	P.0.8	P.1.0
	Relative biomass					
Seals	1	0.9843	0.9684	0.9524	0.9363	0.9199
Cetaceans	1	0.9220	0.8397	0.7532	0.6621	0.5661
Birds	1	0.9854	0.9705	0.9553	0.9399	0.9242
Sharks	1	1.0007	1.0014	1.0022	1.0029	1.0040
Rays and skates	1	0.9999	0.9998	0.9996	0.9995	0.9993
Cod	1	1.0011	1.0023	1.0035	1.0047	1.0060
Haddock	1	1.0002	1.0003	1.0005	1.0006	1.0008
Saithe	1	1.0003	1.0006	1.0009	1.0011	1.0016
Whiting	1	1.0010	1.0021	1.0033	1.0045	1.0058
Other demersals	1	1.0024	1.0048	1.0074	1.0101	1.0129
Flatfish	1	0.9994	0.9987	0.9981	0.9974	0.9967
Mackerel	1	0.9999	0.9999	0.9999	0.9999	0.9999
Herring	1	0.9995	0.9989	0.9983	0.9977	0.9970
Sandeels	1	1.0026	1.0054	1.0086	1.0121	1.0160
Other pelagic	1	1.0031	1.0063	1.0097	1.0132	1.0168
Crabs and lobsters	1	0.9998	0.9996	0.9994	0.9991	0.9989
Nephrops	1	0.9985	0.9971	0.9955	0.9939	0.9922
Prawns and shrimp	1	0.9993	0.9985	0.9977	0.9968	0.9960
Cephalopods	1	0.9998	0.9995	0.9993	0.9991	0.9989
Other invertebrates	1	1.0002	1.0003	1.0005	1.0007	1.0008
Large zooplankton	1	0.9996	0.9992	0.9988	0.9983	0.9979
Small zooplankton	1	1.0003	1.0006	1.0010	1.0013	1.0017
Phytoplankton	1	1.0000	1.0000	1.0000	1.0000	1.0000
Detritus	1	1.0000	1.0000	1.0000	0.9999	0.9999

Figure 34. Pressure region (red rectangle) assigned to t

Table 40. Functional group relative biomass changes with increasing strengths of surface disturbance pressure in the Clyde Sea Ecospace model.

Functional Group	No surface disturbance	P.0.2	P.0.4	P.0.6	P.0.8	P.1.0
	Relative biomass					
Seals	1	0.9636	0.9479	0.9321	0.9162	0.9001
Cetaceans	1	0.9898	0.9741	0.9583	0.9424	0.9263
Birds	1	1.0139	1.0141	1.0142	1.0143	1.0143
Sharks	1	1.1310	1.1312	1.1313	1.1315	1.1318
Rays and skates	1	1.0014	1.0014	1.0014	1.0014	1.0014
Cod	1	0.9582	0.9588	0.9594	0.9600	0.9606
Haddock	1	1.0273	1.0277	1.0281	1.0285	1.0289
Saithe	1	0.9837	0.9838	0.9839	0.9840	0.9841
Whiting	1	1.0068	1.0073	1.0078	1.0082	1.0087
Other demersals	1	0.9877	0.9885	0.9892	0.9899	0.9906
Flatfish	1	0.9476	0.9476	0.9476	0.9475	0.9475
Mackerel	1	1.0113	1.0113	1.0114	1.0114	1.0114
Herring	1	0.9734	0.9732	0.9731	0.9730	0.9728
Sandeels	1	1.0253	1.0264	1.0276	1.0287	1.0299
Other pelagic	1	0.9905	0.9911	0.9917	0.9923	0.9930
Crabs and lobsters	1	1.0414	1.0413	1.0413	1.0412	1.0411
Nephrops	1	1.0974	1.0971	1.0969	1.0967	1.0964
Prawns and shrimp	1	1.0331	1.0329	1.0327	1.0326	1.0324
Cephalopods	1	0.9678	0.9678	0.9678	0.9678	0.9679
Other invertebrates	1	1.0255	1.0256	1.0256	1.0256	1.0257
Large zooplankton	1	0.9714	0.9713	0.9712	0.9711	0.9710
Small zooplankton	1	0.9886	0.9887	0.9888	0.9888	0.9889
Phytoplankton	1	0.9990	0.9990	0.9990	0.9990	0.9990
Detritus	1	0.9943	0.9943	0.9943	0.9943	0.9943

Table 41. Functional group relative biomass changes with increasing strengths of bottom disturbance pressure in the Clyde Sea Ecospace model.

Functional Group	No bottom disturbance	P.0.2	P.0.4	P.0.6	P.0.8	P.1.0
	Relative biomass					
Seals	1	0.9783	0.9774	0.9765	0.9755	0.9745
Cetaceans	1	1.0054	1.0055	1.0056	1.0057	1.0057
Birds	1	1.0136	1.0138	1.0140	1.0140	1.0141
Sharks	1	1.1279	1.1246	1.1215	1.1195	1.1274
Rays and skates	1	0.9957	0.9887	0.9795	0.9671	0.9506
Cod	1	0.9554	0.9533	0.9509	0.9481	0.9448
Haddock	1	1.0219	1.0161	1.0091	1.0006	0.9903
Saithe	1	0.9834	0.9829	0.9823	0.9813	0.9798
Whiting	1	1.0057	1.0054	1.0053	1.0054	1.0058
Other demersals	1	0.9835	0.9796	0.9752	0.9702	0.9665
Flatfish	1	0.9289	0.9057	0.8779	0.8466	0.8117
Mackerel	1	1.0116	1.0122	1.0131	1.0142	1.0155
Herring	1	0.9713	0.9689	0.9663	0.9635	0.9606
Sandeels	1	1.0227	1.0200	1.0158	1.0095	1.0001
Other pelagic	1	0.9882	0.9854	0.9809	0.9743	0.9648
Crabs and lobsters	1	0.9811	0.9117	0.8320	0.7404	0.6283
Nephrops	1	1.0947	1.0916	1.0879	1.0837	1.0781
Prawns and shrimp	1	1.0256	1.0144	0.9986	0.9765	0.9464
Cephalopods	1	0.9691	0.9714	0.9748	0.9797	0.9864
Other invertebrates	1	0.9736	0.9146	0.8476	0.7712	0.6838
Large zooplankton	1	0.9739	0.9771	0.9812	0.9865	0.9934
Small zooplankton	1	0.9968	1.0066	1.0185	1.0329	1.0503
Phytoplankton	1	1.0019	1.0053	1.0092	1.0136	1.0187
Detritus	1	1.0020	1.0109	1.0214	1.0337	1.0482

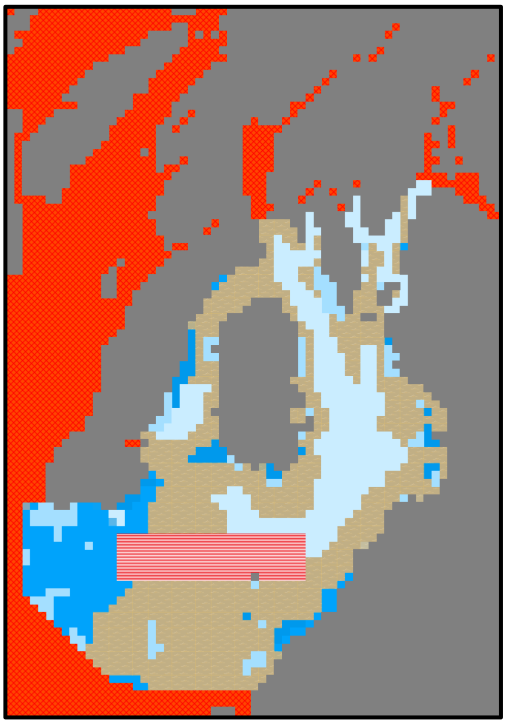


Figure 35. Artificial substrate region (red rectangle) assigned to the Clyde Sea Ecospace model.

Table 42. Biomass of functional groups within a region of the Clyde Sea model when that region does and does not include a designated artificial structure (A.S.).

Functional Group	Biomass		
	Without A.S.	With A.S.	Ratio
Herring	2.035	1.931	0.949
Flatfish	1.339	1.280	0.956
Cephalopods	0.579	0.557	0.962
Large zooplankton	8.959	8.686	0.970
Other pelagic	9.136	8.958	0.981
Small zooplankton	5.534	5.435	0.982
Detritus	99.992	98.914	0.989
Phytoplankton	80.205	79.943	0.997
Cod	0.338	0.338	1.001
Mackerel	0.759	0.760	1.003
Rays and skates	0.307	0.309	1.004
Saithe	0.132	0.133	1.008
Sandeels	1.429	1.446	1.012
Seals	0.053	0.054	1.017
Prawns and shrimp	16.063	16.565	1.031
Other demersals	3.016	3.154	1.046
Other invertebrates	33.946	35.831	1.056
Cetaceans	0.129	0.137	1.062
Whiting	1.046	1.116	1.068
Birds	0.006	0.006	1.071
Nephrops	4.924	5.428	1.102
Crabs and lobsters	1.970	2.193	1.113
Haddock	0.410	0.459	1.118
Sharks	0.295	0.331	1.121

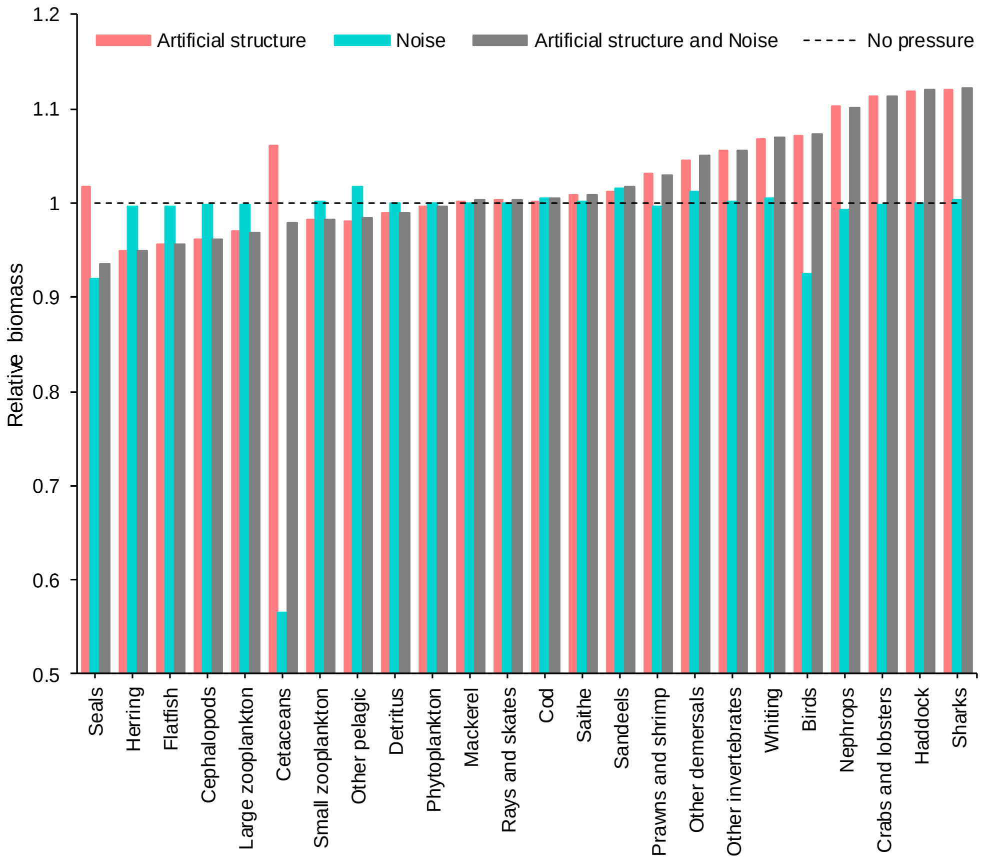


Figure 36. Relative biomass of functional groups in the Clyde Sea Ecospace model when the model area includes noise pressure, an artificial structure and both.

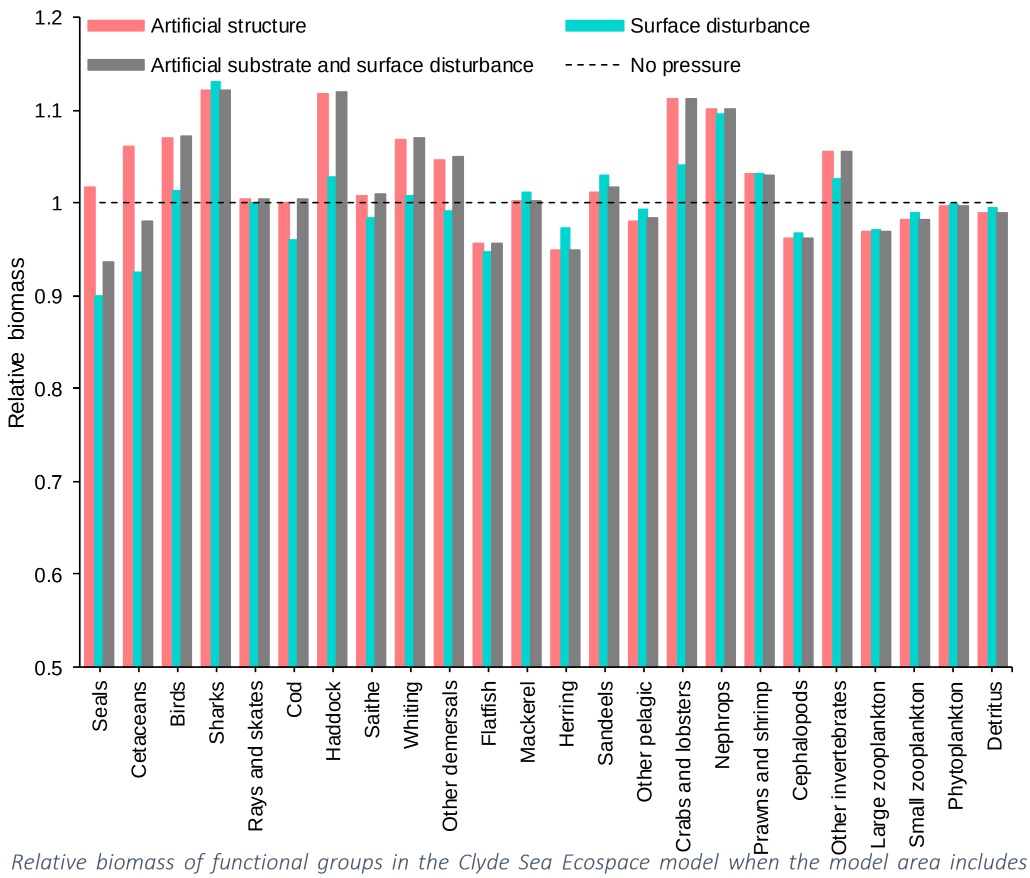


Figure 37. Relative biomass of functional groups in the Clyde Sea Ecospace model when the model area includes surface disturbance, an artificial structure and both.

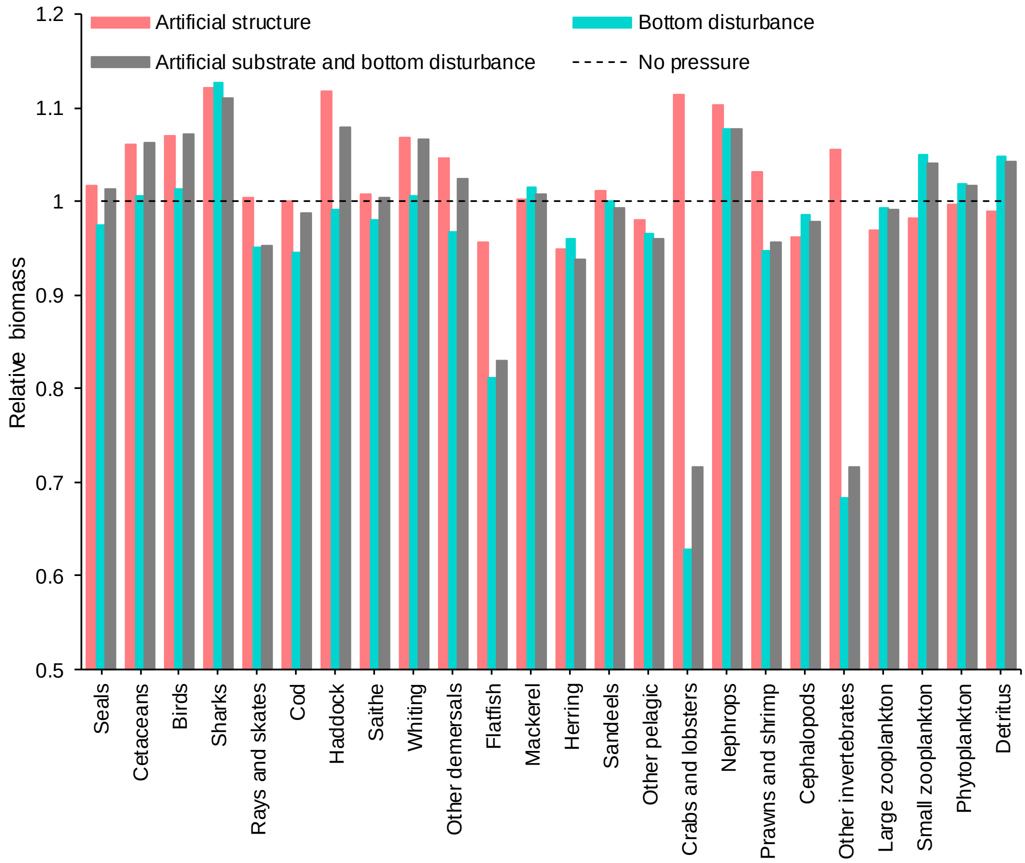


Figure 38. Relative biomass of functional groups in the Clyde Sea Ecospace model when the model area includes bottom disturbance, an artificial structure and both.

MSP tool

The MSP tools plugin has six tabs: 'Settings', 'Information', 'Pressures', 'Outcomes', MEL emulator', 'About MSP tools'.

1: Settings

Game: Clyde Sea
Spin-up years: 10
Run years: 1000
Close MPA at 0.5 cell coverage
DO NOT include Ecospace diversity indicator calculations

Validation

- Game name unique
- No Ecosim time series loaded
- No Ecosim forcing patterns
- No Ecosim fishing patterns
- No Ecospace time series loaded

2: Information

Ecopath version: 6.6

Number of rows: 93
Number of columns: 67
Basemap resolution: 1500
Assume square cells: YES
Georeferenced: YES (Lat: 3743056.000; Lon:3317866.000)

Habitat source: Emodned (Magali)
Habitats included: Mud, Rcok, Sand, Coarse sediment, Mixed sediment, Artificial habitat (6)
Habitat foragis usage included: YES
Depth functional responses included: YES

Number of fleets:5
Designated ports: NONE
Number of MPAs: 5

Environmental pressures: Noise, Surface disturbance, Bottom disturbance (3)

3: Pressures

Nine pressures were included in the Clyde Sea MSP model (Table 43). These pressures were initially created during the construction of the Clyde Sea Ecospace model by defining MPAs and environmental drivers. The associated data to drive these pressures was provided by NHTV.

Table 43. Pressures and their assigned drivers in the Clyde Sea MSP game.

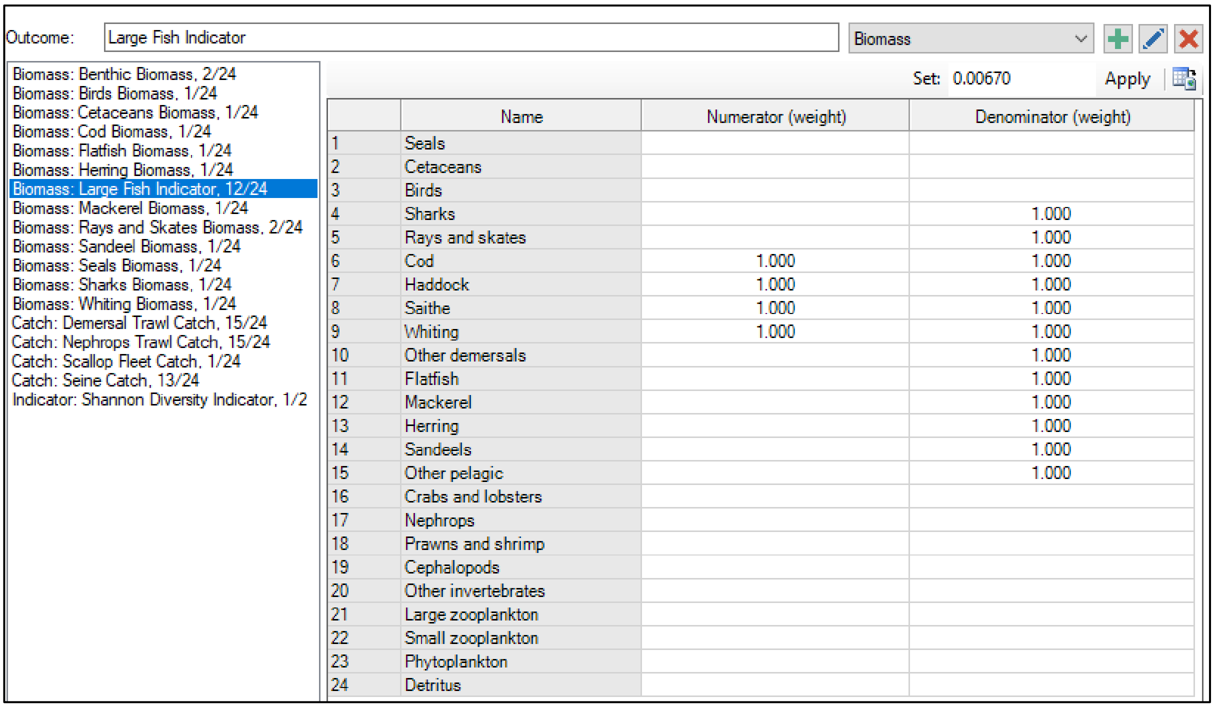
	MSP pressure	EwE driver
1	Noise	Map of Env. Driver "Noise"
2	Bottom disturbance	Map of Env. Driver "Surface disturbance"
3	Surface disturbance	Map of Env. Driver "Bottom disturbance"
4	Artificial habitat	Map of Habitat "Artificial substrate"
5	Protection Demersal trawl	Map of MPA "MPA 1: Demersal trawl"
6	Protection Scallop fleet	Map of MPA "MPA 2: Scallop fleet"
7	Protection Nephrops fleet	Map of MPA "MPA 5: Nephrops fleet"
8	Protection Pots and creels	Map of MPA "MPA 7: Pots and creel"
9	Protection Seine	Map of MPA "MPA 8: Seine"

4: Outcomes

The game deliverables are determined by assigning 'outcomes' in the MSP tool. Outcomes can provide ecosystem derived information for biomass, catch, effort and biodiversity (indicators). The Clyde Sea model includes 22 outcomes: 16 biomasses, 5 catches and 1 indicator (Table 44). Biomass outcomes can include a single functional group (i.e. cod biomass) or a combination of multiple groups (i.e. Large fish indicator). To assign a functional group to an outcome, one simply has to enter a '1' (present) under the Numerator or Denominator column in the appropriate row (Figure 39). The assignment of catch outcomes can differ slightly. If, like in the Clyde Sea model, different fleets catch the same functional groups, it is necessary to assign functional groups to outcomes based on the proportion of their total catch attributable to the specific fleet you are designing an outcome for (Figure 40). Assigning a '1' would result in the entire catch of that functional group being added to the outcome of a single fleet, which may only in fact be responsible for a small portion of that groups fishing mortality.

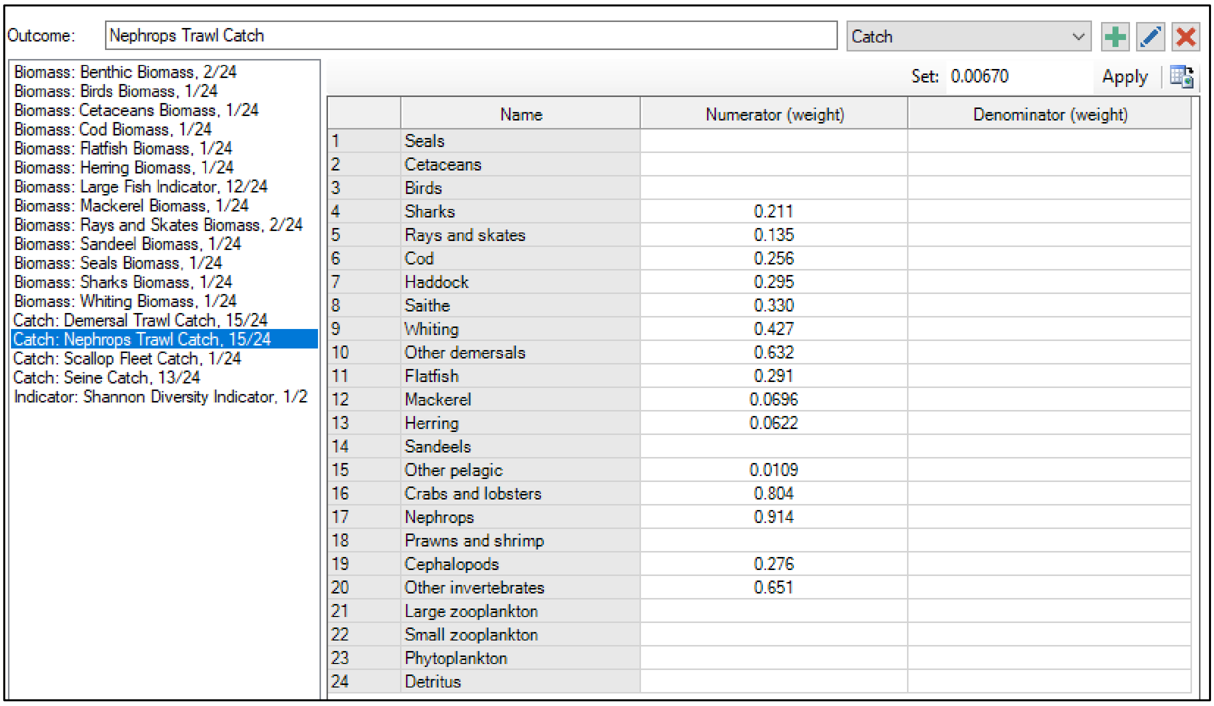
Table 44. Outcomes of the Clyde Sea MSP game

Category	Outcome	Functional groups included (/24)	Contributing groups
Biomass	Benthic biomass	2	Crabs and Lobsters; Other invertebrates
	Cetacean biomass	1	Cetaceans
	Cod biomass	1	Cod
	Demersal biomass	1	Other demersals
	Elasmobranch biomass	2	Sharks; Rays and skates
	Flatfish biomass	1	Flatfish
	Haddock biomass	1	Haddock
	Herring biomass	1	Herring
	Mackerel biomass	1	Mackerel
	Nephrops biomass	1	Nephrops
	Saithe biomass	1	Saithe
	Sandeel biomass	1	Sandeel
	Seabird biomass	1	Seabirds
	Seal biomass	1	Seals
	Whiting biomass	1	Whiting
	Large fish indicator	12	Sharks; Rays and skates; Cod; Haddock; Saithe; Whiting; Other demersals; Flatfish; Mackerel; Herring; Sandeels; Other pelagic
Catch	Demersal trawl	14	Sharks; Rays and skates; Cod; Haddock; Saithe; Whiting; Other demersals; Flatfish; Mackerel; Herring; Other pelagic; Nephrops; Cephalopods; Other invertebrates
	Nephrops trawl	14	Sharks; Rays and skates; Cod; Haddock; Saithe; Whiting; Other demersals; Flatfish; Mackerel; Herring; Other pelagic; Nephrops; Cephalopods; Other invertebrates
	Pots and creel	2	Crabs and lobsters; Nephrops
	Scallop dredge	1	Other invertebrates
	Seine	13	Sharks; Rays and skates; Cod; Haddock; Saithe; Whiting; Other demersals; Flatfish; Mackerel; Herring; Other pelagic; Nephrops; Cephalopods
Indicator	Shannon diversity	-	-



	Name	Numerator (weight)	Denominator (weight)
1	Seals		
2	Cetaceans		
3	Birds		
4	Sharks		1.000
5	Rays and skates		1.000
6	Cod	1.000	1.000
7	Haddock	1.000	1.000
8	Saithe	1.000	1.000
9	Whiting	1.000	1.000
10	Other demersals		1.000
11	Flatfish		1.000
12	Mackerel		1.000
13	Herring		1.000
14	Sandeels		1.000
15	Other pelagic		1.000
16	Crabs and lobsters		
17	Nephrops		
18	Prawns and shrimp		
19	Cephalopods		
20	Other invertebrates		
21	Large zooplankton		
22	Small zooplankton		
23	Phytoplankton		
24	Detritus		

Figure 39. The determination of 'Outcomes' in the Clyde Sea MSP model. The screenshot shows the allocation of functional groups to the biomass outcome 'Large Fish Indicator'. To feed information from certain groups into the final outcome, a 1 (present) is added to the appropriate row and column.



	Name	Numerator (weight)	Denominator (weight)
1	Seals		
2	Cetaceans		
3	Birds		
4	Sharks	0.211	
5	Rays and skates	0.135	
6	Cod	0.256	
7	Haddock	0.295	
8	Saithe	0.330	
9	Whiting	0.427	
10	Other demersals	0.632	
11	Flatfish	0.291	
12	Mackerel	0.0696	
13	Herring	0.0622	
14	Sandeels		
15	Other pelagic	0.0109	
16	Crabs and lobsters	0.804	
17	Nephrops	0.914	
18	Prawns and shrimp		
19	Cephalopods	0.276	
20	Other invertebrates	0.651	
21	Large zooplankton		
22	Small zooplankton		
23	Phytoplankton		
24	Detritus		

Figure 40. The determination of 'Outcomes' in the Clyde Sea MSP model. The screenshot shows the allocation of functional groups to the catch outcome for the 'Nephrops Trawl'. Values assigned to functional groups represent the proportion of their total catch (from all fleets) attributable to the Nephrops fleet.

5: MEL emulator

Under the MEL (MSP-EwE link) emulator, test data is linked to the appropriate MSP pressure. Test data sets were generated by NHTV and attached as TIF files. The pressure layers were incorporated into the Clyde Sea Ecospace model. The coverage of fleet specific MPAs derived from the NHTV pressure layers is shown in Figure 41. The environmental driver layers for noise, surface distrubance and pressure disturbance and shown in Figure 42 and the location of artificial structure in Figure 43.

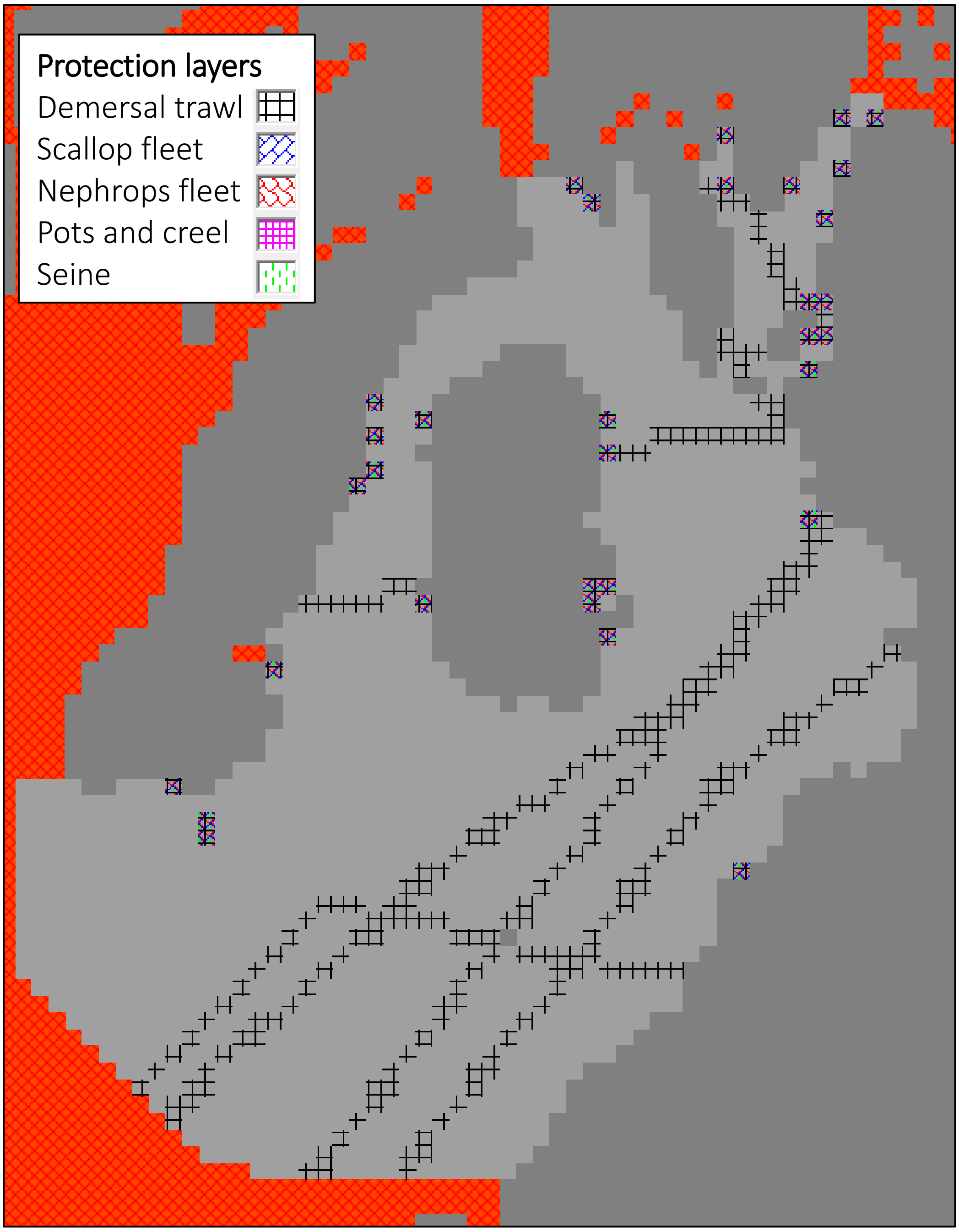


Figure 41. MPA layers for fleets in the Clyde Sea model. Protection layers (TIF files) were linked to their EwE counterparts under the MEL emulator tab in the MSP tool.

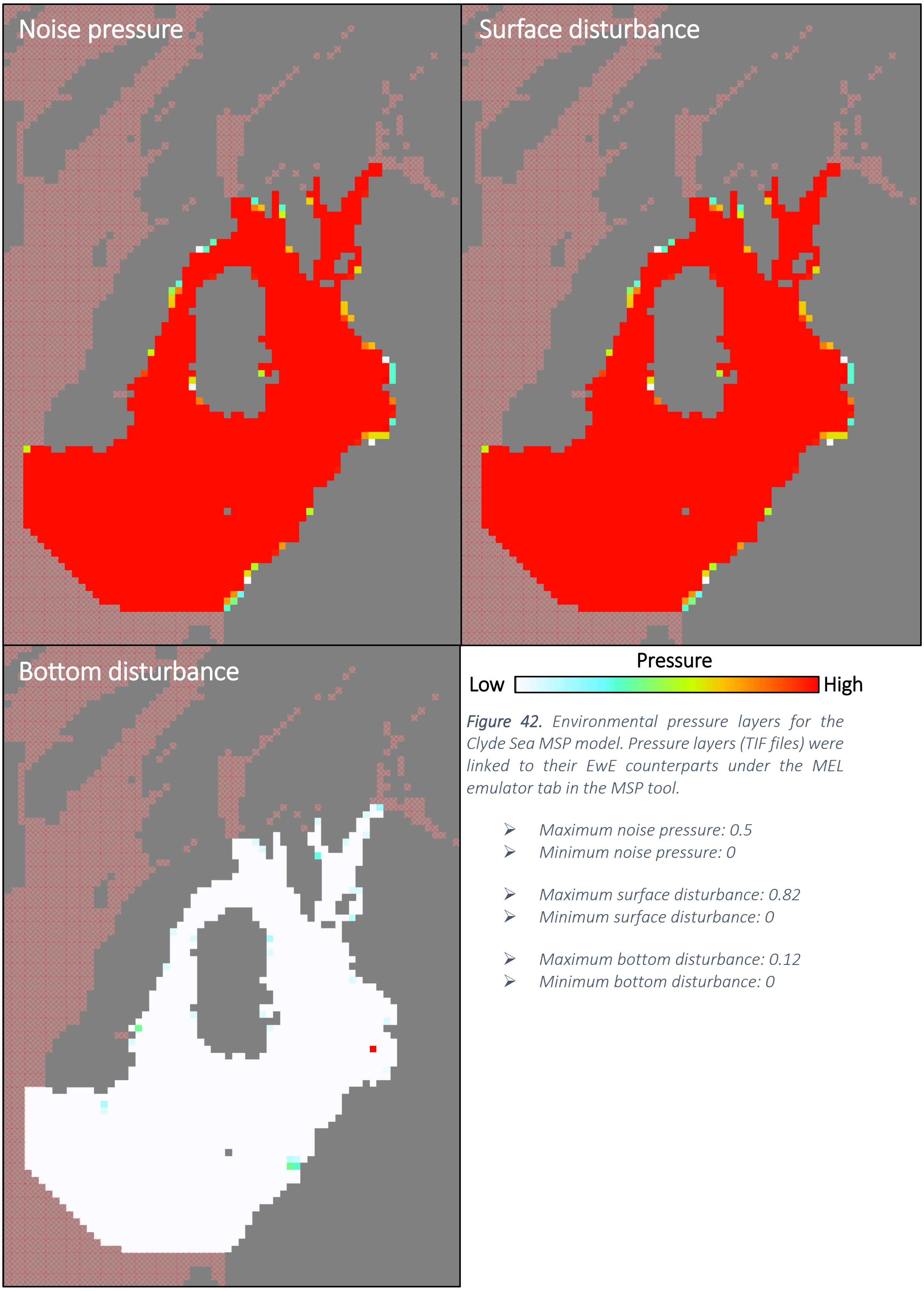


Figure 42. Environmental pressure layers for the Clyde Sea MSP model. Pressure layers (TIF files) were linked to their EwE counterparts under the MEL emulator tab in the MSP tool.

- *Maximum noise pressure: 0.5*
- *Minimum noise pressure: 0*

- *Maximum surface disturbance: 0.82*
- *Minimum surface disturbance: 0*

- *Maximum bottom disturbance: 0.12*
- *Minimum bottom disturbance: 0*

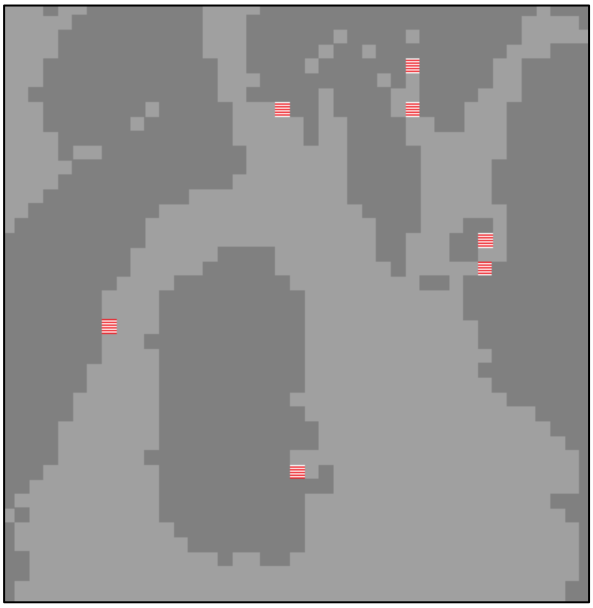


Figure 43: Location of artificial structures in the Clyde Sea MSP model. The artificial structure layer (TIF file) was linked to its EwE counterparts under the MEL emulator tab in the MSP tool.

Ecospace output with MSP layers

Biomass maps for functional groups in the Clyde Sea model after 24 years of run time with MSP startup pressures applied are shown in Figure 44. The spinup period remains similar to the results produced when MSP pressures aren't included (roughly 10 years; Figure 45). Ecospace results were used to compare the dynamics of the system with and without MSP pressures applied. The biomass of functional groups remains relatively unchanged, with a maximum proportional change of 0.06 (6% increase in Nephrops biomass) after applying MSP pressures (Figure 45). Catch also remains consistent, with a maximum proportional change of 0.03 (3% increase in Nephrops fleet catch) after applying MSP pressures (Figure 46).

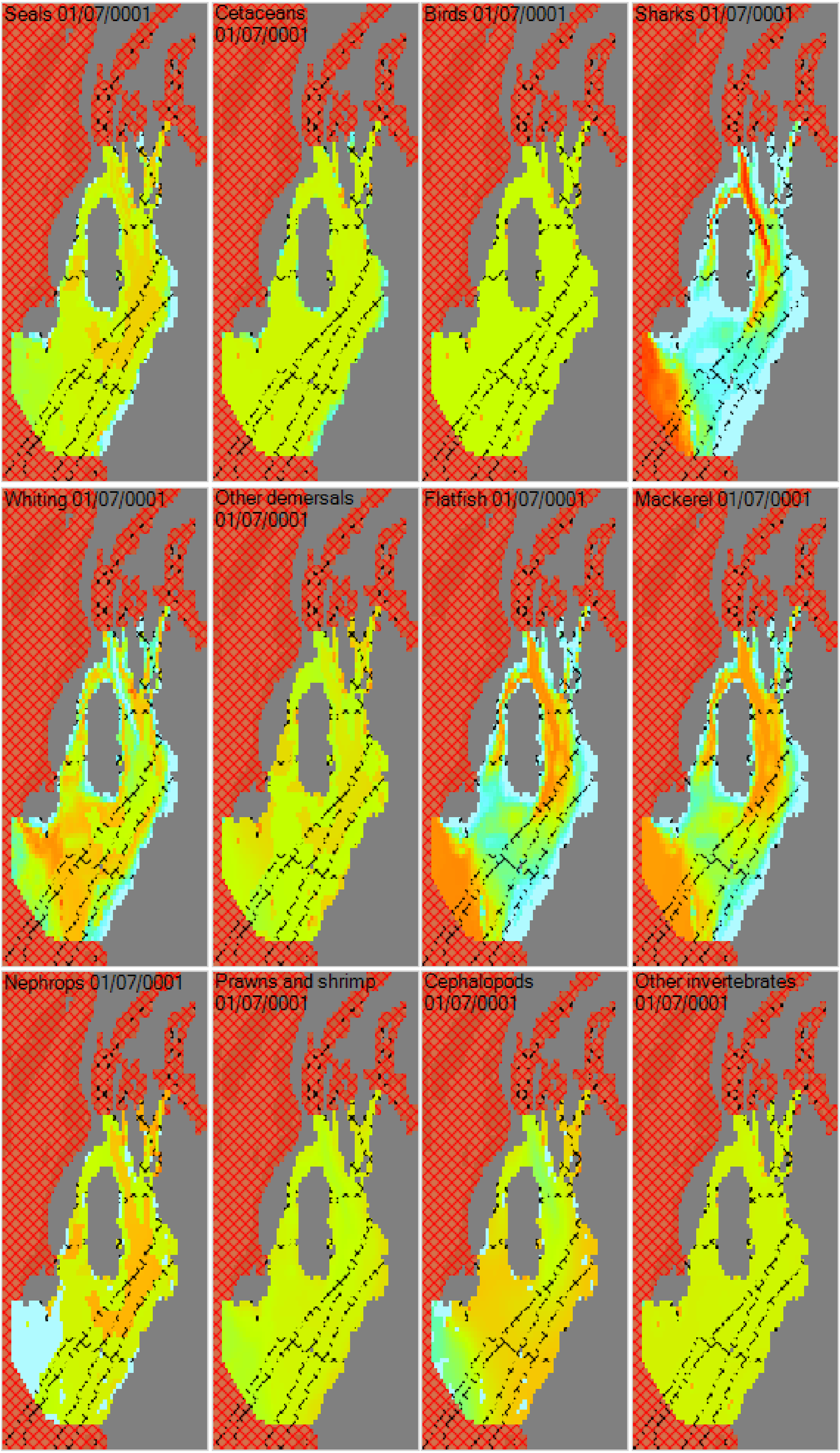


Figure 44. Relative biomass of functional groups in the Clyde Sea Ecospace model with MSP pressures after 24 years of run time.

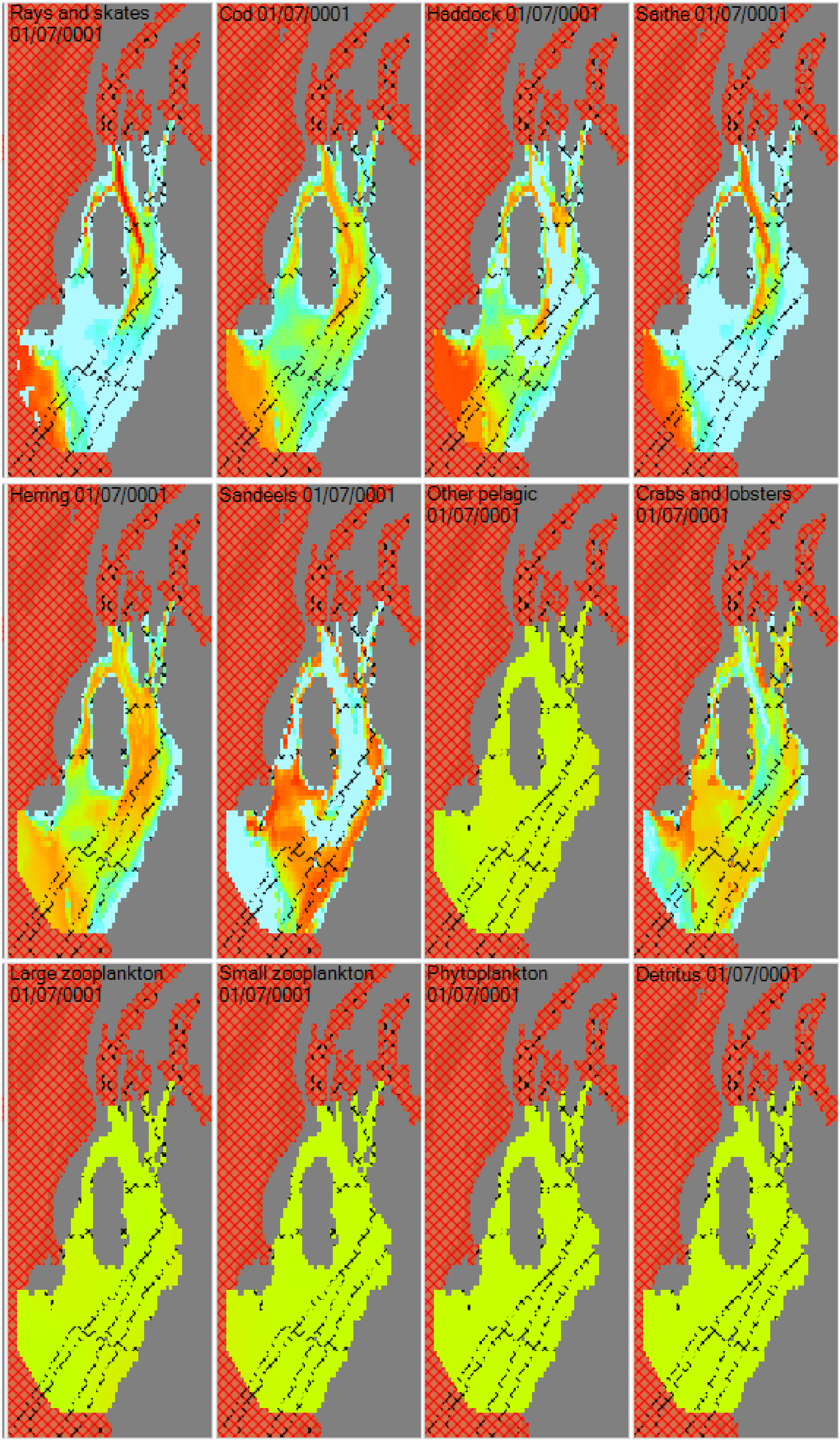


Figure 44. Continued

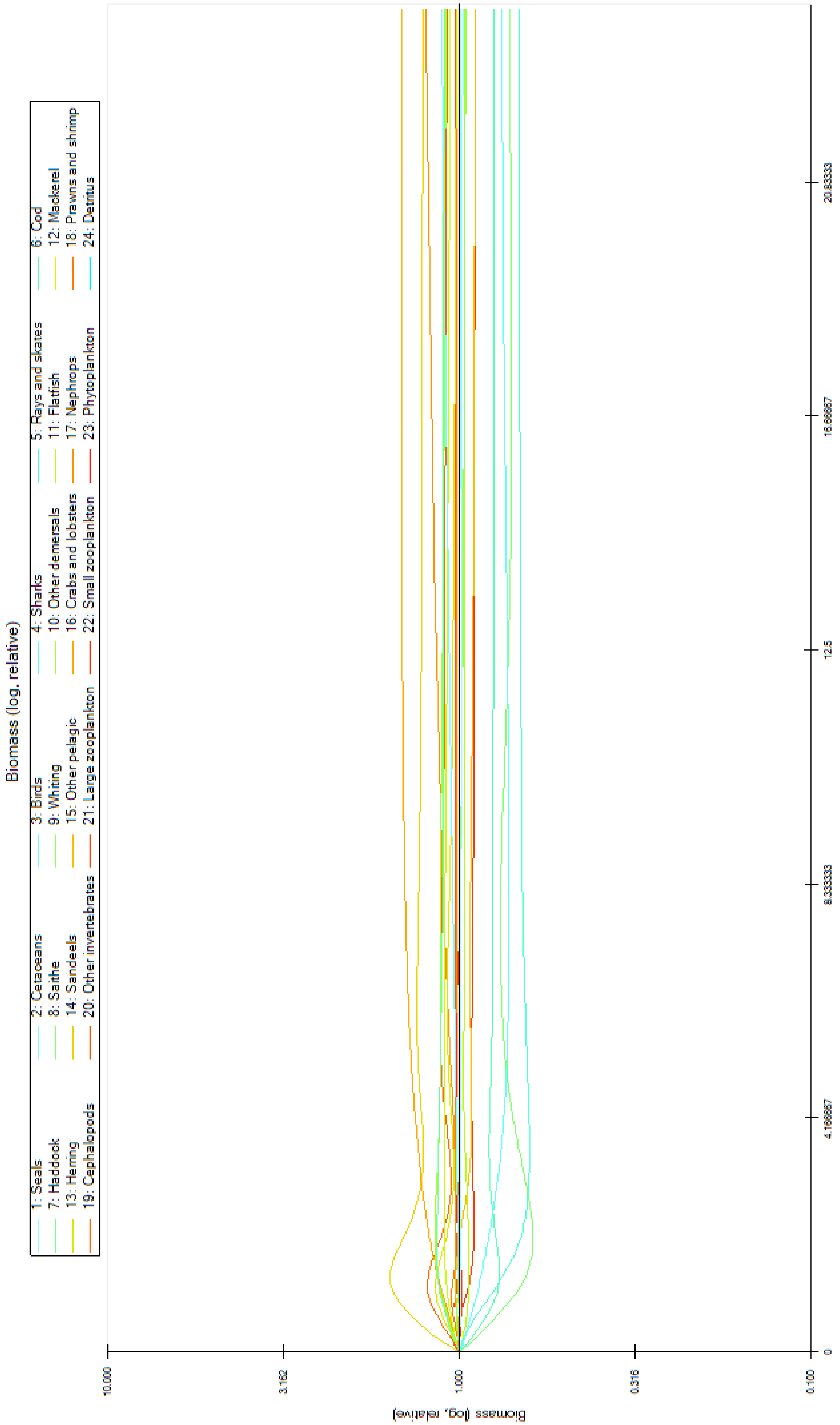


Figure 45. Relative biomass of functional groups in the Clyde Sea Ecospace model with MSP pressures applied. The model shows stability after roughly 10 years.

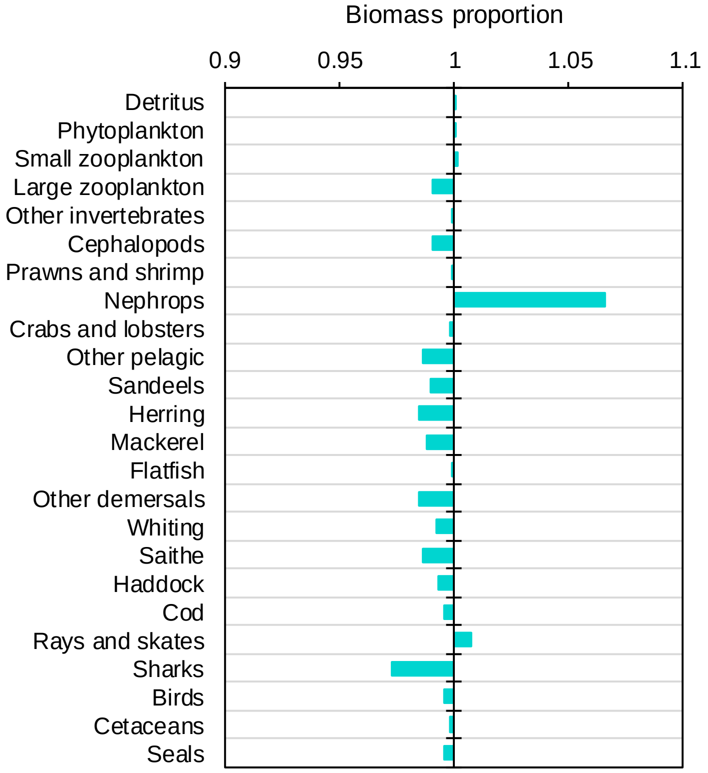


Figure 45. Proportional change in biomass of functional groups in the Clyde Sea when MSP pressures are applied. Values for before and after were taken after a run time of 24 years.

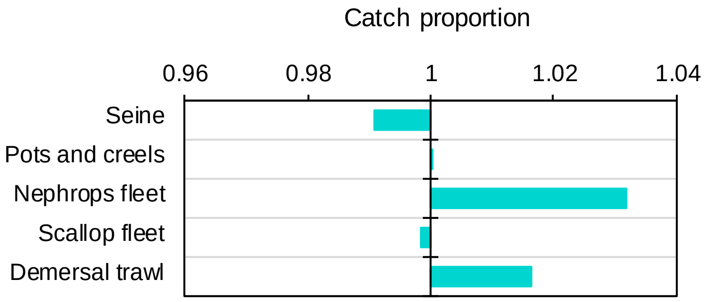


Figure 46. Proportional change in the catch of fishing fleets in the Clyde Sea when MSP pressures are applied. Values for before and after were taken after a run time of 24 years.

References

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