Combined effects of eutrophication, fishery and species introductions in a temperate coastal ecosystem: Modelling changes in the Archipelago Sea food web 2000-2016

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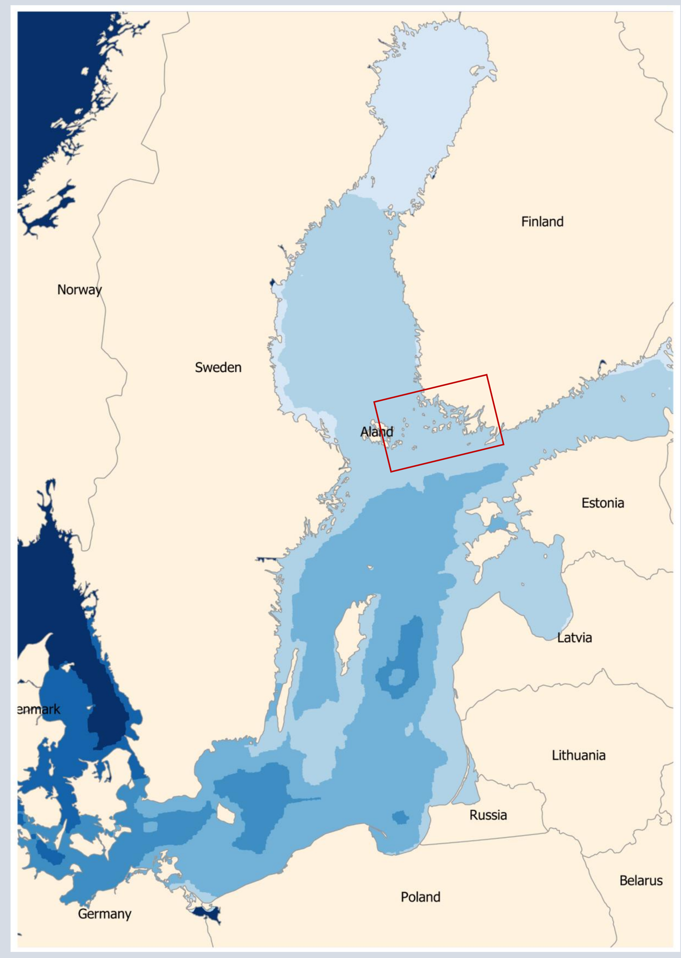
WATER PROTECTION PROGRAMME

Introduction

- The Archipelago Sea is a diverse *coastal ecosystem* where a fragmented landscape results in high abiotic and biotic diversity
- The region also provides a *variety of ecosystem services* (e.g., hunting and fishing, tourism, nursery habitats) while it is *greatly impacted by humans* via nutrient loads from a variety of sources, construction activities, and fishing
- In addition, several *non-indigenous species* (NIS) have been established in the Archipelago Sea during the past few decades
- The Archipelago Sea is characterized by gradients such as depth, salinity, and wave exposure, which impact greatly the local species composition
- It provides nursery habitats for many species and is important for migrating water birds and marine mammals
- The Archipelago Sea food web is a mixture of fresh water and marine species



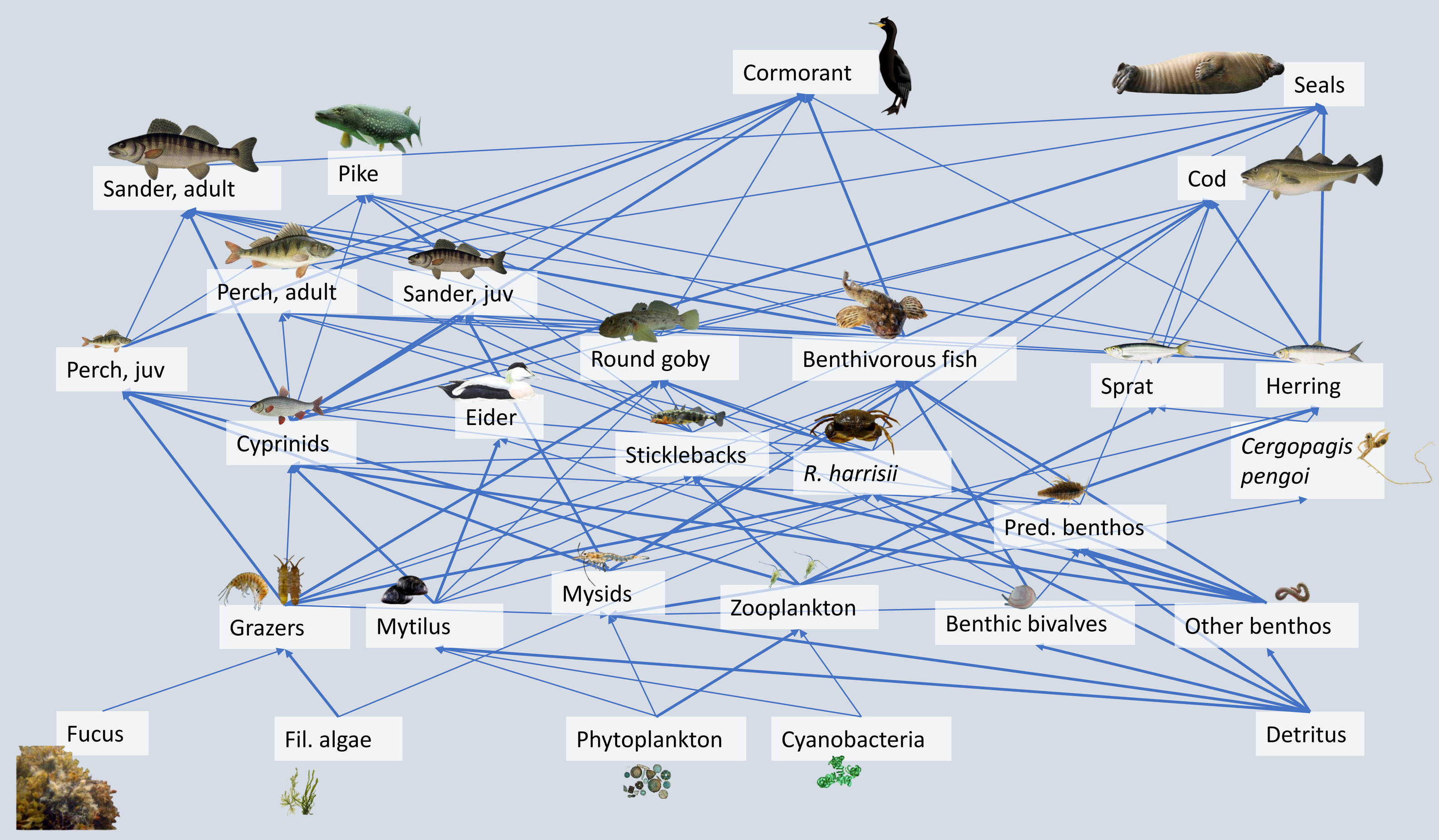


Figure 1. Food web represented by the Archipelago Sea model

- To understand the complex system and its drivers better, *we modelled how the Archipelago Sea* food web has changed both in terms of structure and functioning under the years 2000 to 2016 using Ecopath with Ecosim (EwE)
- *The model describes the temporal dynamics of 29 functional groups* ranging from detritus and primary producers (both micro and macroalgae) to seals and birds for the years 2000 to 2016
- The invasive species present in the area were introduced during the modelling period using the approach described by Langseth et al. (2012)
- The cormorant biomass was forced since its controlled by factors outside the model

	Group name	TL	Hab area (proportion)	Biomass (t/km²)	P/B or Z (rate/year)	C/B (rate/year)	EE	P/C (rate/year)	BA (t/km²)	BA (rate/year)	Immigration/ Emigration (t/km²/year)	Unassim. consumption	Feeding time adjust rate [0,1]	Predator effect on feeding time [0,1]	Switching power parameter [0,2]
1	Seals	4.09	1	0.02	0.10	16.28	0.89	0.01	1.40E-03	0.08		0.2	0.1	0	2
2	Cormorant	4.17	0.5	4.52E-06	0.20	66.32	0.78	0.00	7.04E-07	0.16	4.50E-08	0.2	0.5	0	2
3	Gadus morhua	3.76	1	3.60E-05	0.75	3.81	0.99	0.20			5.00E-06	0.2	0.5	1	0
	Sander lucioperca														
4	Juvenile Sander lucioperca	3.84	1	0.44	1.10	7.57	0.26	0.15				0.2	1	0	0
5	Adult Sander lucioperca	4.10	1	0.14	1.00	3.72	0.50	0.27				0.2	0.5	1	0
6	Esox lucius	4.09	1	0.38	0.57	2.50	0.63	0.23				0.2	0.5	1	0
	Perca fluviatilis														
7	Juvenile Perca fluviatilis	3.25	1	0.68	0.82	6.18	0.47	0.13				0.2	1	0	0
8	Adult Perca fluviatilis	4.07	1	0.84	0.70	3.50	0.40	0.20				0.2	0.5	1	0
9	Benthivorous birds	3.00	1	0.01	0.36	18.25	0.68	0.02	-5.70E-04	-0.10		0.2	0.5	0	0
10	Benthivorous fish	3.16	1	1.69	0.84	4.21	0.57	0.20				0.2	0.5	1	2
11	Neogobius melanostomus	3.04	1	8.14E-05	4.24	5.90	1.00	0.72				0.2	1	1	2
12	Clupea harengus	3.03	1	5.85	1.19	4.40	0.53	0.27			-0.64	0.2	1	1	0
13	Sprattus sprattus	3.03	1	2.08	1.55	6.77	0.35	0.23			-0.49	0.2	1	1	0
14	Rhithropanopeus harrisii	2.82	1	8.65E-05	4.30	7.00	0.98	0.61				0.3	1	0.5	2
15	Gasterosteus aculeatus	3.03	1	0.85	0.77	3.85	0.92	0.20				0.2	1	1	2
16	Cyprinids	3.06	1	10.00	0.45	2.10	0.87	0.21				0.2	1	1	0
17	Cercopagis pengoi	3.00	1	0.00	10.00	40.00	1.00	0.25				0.3	0	0	0
18	Mysids	2.62	1	1.68	4.50	14.89	0.75	0.30				0.3	0	0.5	0
19	Predatory benthos	2.49	1	1.95	2.00	9.70	0.78	0.21				0.3	0	0.5	0
20	Invertebrate grazers	2.00	1	5.27	2.70	13.88	0.54	0.19				0.2	0	0.5	0
21	Mytilus trossulus	2.00	1	8.60	1.75	8.73	0.42	0.20				0.2	0	0.5	0
22	Benthic bivalves	2.00	1	25.00	0.40	2.00	0.63	0.20				0.2	0	0.5	0
23	Other benthos	2.00	1	6.00	6.17	31.17	0.46	0.20				0.2	0	0.5	0
24	Zooplankton	2.00	1	5.23	20.00	88.00	0.53	0.23				0.4	0	0.5	0
25	Fucus vesiculosus	1.00	1	3.50	3.30		0.63						0.5	0	0
26	Filamentous algae	1.00	1	4.00	23.00		0.72						0.5	0	0
27	Phytoplankton	1.00	1	7.26	150.00		0.43						0.5	0	0
28	Cyanobacteria	1.00	1	0.11	135.00		0.34						0.5	0	0
29	Detritus	1.00	1	150.00			0.30				-15				

Table 1. Ecopath and Ecosim parameters of the model

- *Environmental forcings* include primary production, nitrogen fixation and temperature (spring and summer), *harvesting is described by seven fleets*, including recreational fishing and hunting

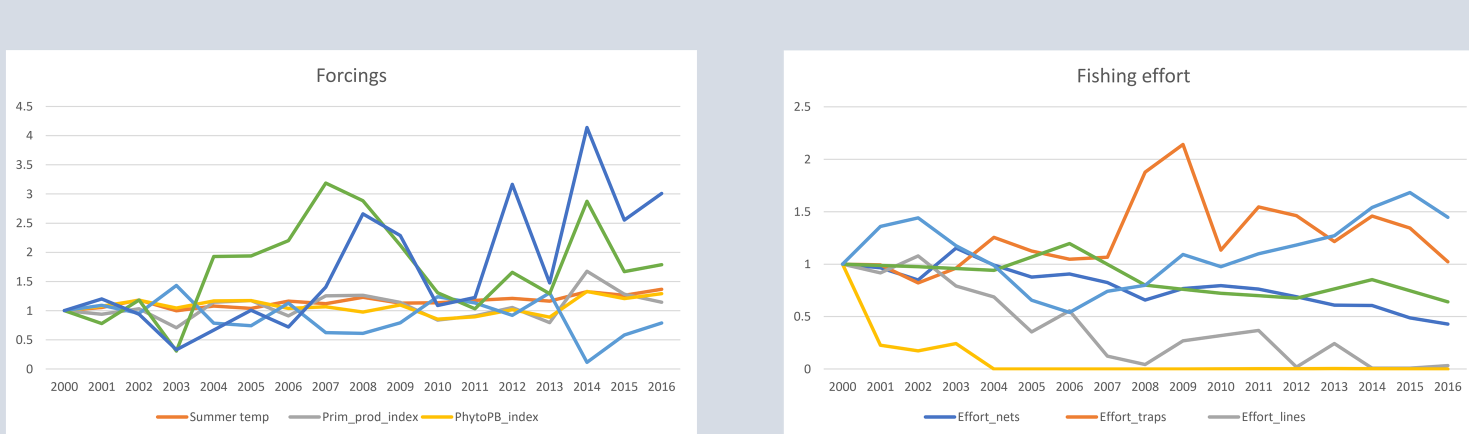
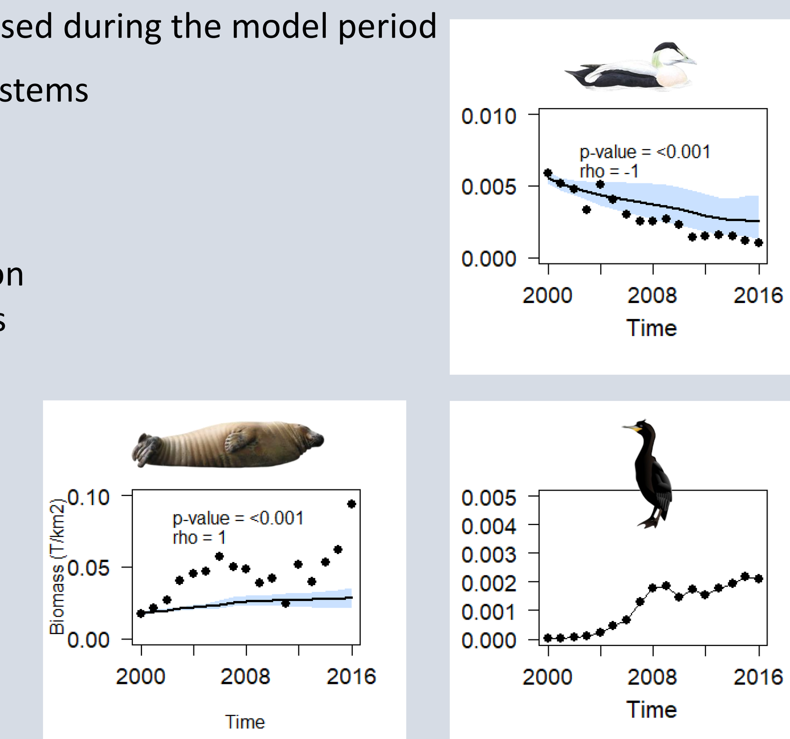


Figure 2. Environmental forcings and fishing effort used in the model simulations

Results

Overall changes in the system

- Changes in *abiotic factors:* Temperatures have increased, especially in the spring
- Changes in *fishing effort:* Gear types have changed, and overall effort decreased, which appear to increase the fish biomass towards year 2016
- Changes in *top predator* biomasses
  - Increases in seals and cormorants
- Decline in benthivorous birds
- *Non-indigenous species* (NIS) biomass has increased during the model period
  - Still at moderate levels compared to other systems
- Fluctuations in *primary production*
  - Fluctuations in nitrogen fixation visible as cyanobacterial blooms and resulting reduction in water transparency impacts *Fucus* biomass
- The model captures the changes moderately
  - Model performance would improve with additional environmental forcings
  - There are also limitations in biomass data as many important taxa, such as sticklebacks, Mysids or littoral invertebrates, are not monitored



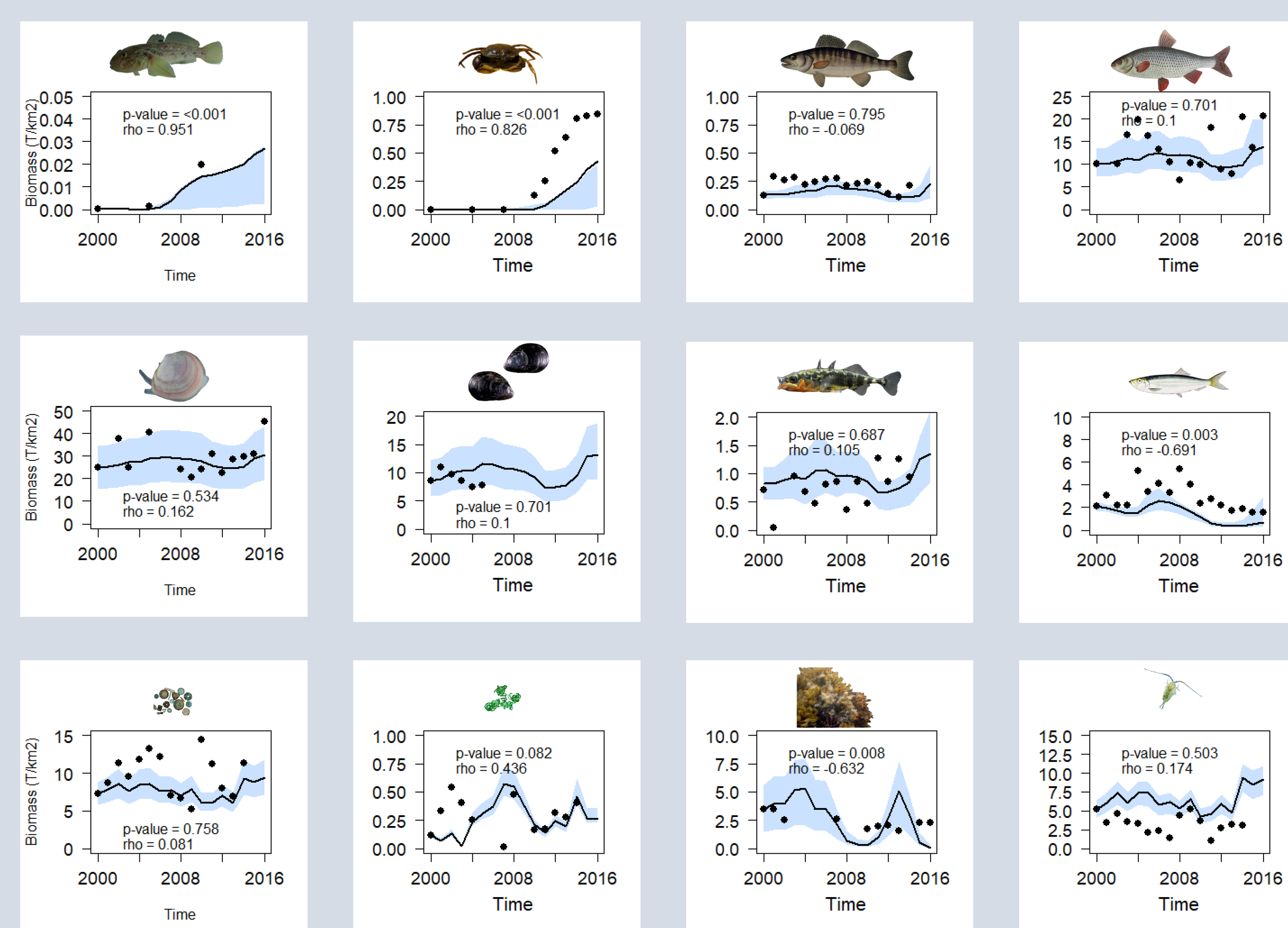


Figure 3. Model fits (solid line) and calibration data (points) for different taxa. Pale blue colour indicates parameter range percentiles (5 and 95)

Ecologial network analysis (ENA)

- The ecological network analysis (ENA) indices show slight changes in the Archipelago Sea ecosystem in 2000-2016
- *Total system throughput* increases
  - Total system throughput is the sum of all flows. It can be seen as the representation of the size of the system concerning flows (Ulanowicz 1986) -> system biomass increases towards 2016
- *Relative ascendency* declines
  - The relative ascendency (A/C) is the ratio of ascendency and capacity. It is negatively related to maturity (Heymans et al. 2014) implying more mature system towards 2016

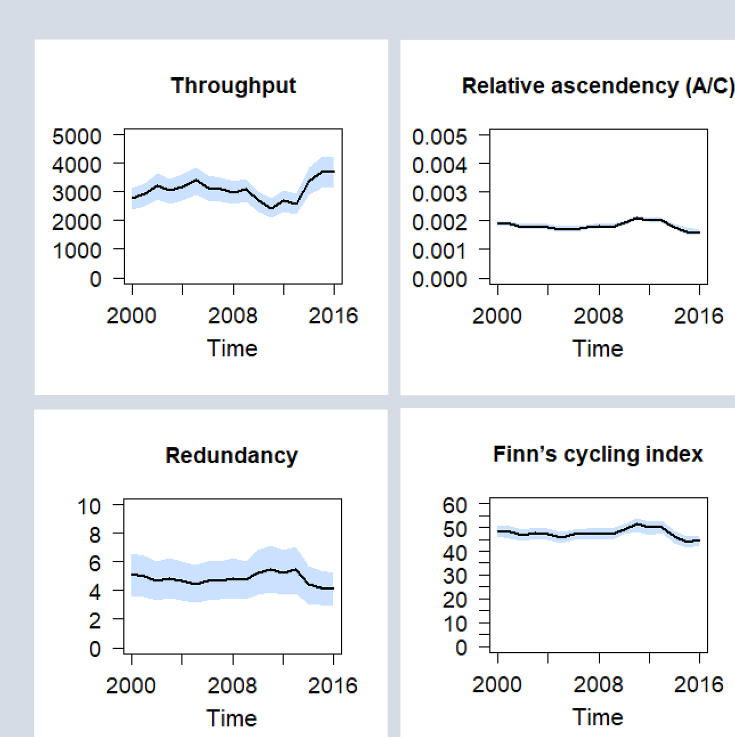


Figure 4. Selected ENA indicators

- *Redundancy* declines
  - The redundancy can be described as an index of the resilience of the system (Heymans et al. 2007). According to Heymans (Heymans 2004) internal overhead can be used as a measure of redundancy and resilience - > Redundancy declines towards 2016
- *Finn's cycling index* decreases
  - The Finn's cycling index (Finn 1976) represents the proportion of total system throughput (TST) that is recycled back to the system. The lower the FCI value is, the longer it takes for the system to recover, especially in a degraded situation (Vasconcellos et al. 1997, Shannon et al. 2009) -> Declining FCI indicates degradation towards 2016
- The results highlight the variability of the system and challenges to identify impacts of cumulative pressures in a coastal system but also point to changing system during the last few years of the analysed time span

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