Alien species, fisheries and Climate Change: Forecasting their cumulative impacts in the South Aegean Sea with ecosystem modeling

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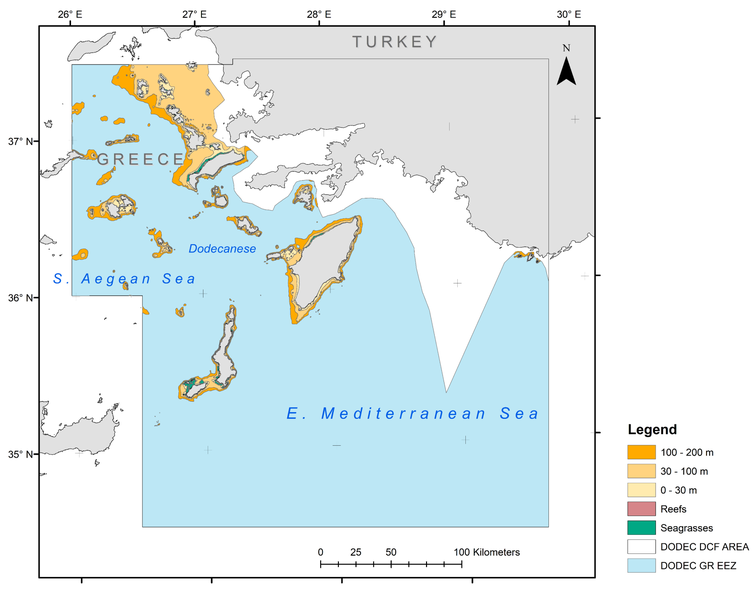
Introduction

- The Mediterranean is a marine biodiversity hotspot, and also a heavily impacted sea due to increasing levels of human pressures[1], significant impacts from Climate Change[2], and biological invasions[3].
- Ecosim is a modeling tool that is increasingly being deployed to forecast ecosystem dynamics and develop future scenarios for the ocean[4].
- In this study, the first Ecosim model for the coastal shelf of the Dodecanese islands was developed with the aim to make predictions of potential future impacts on the food web of scenarios for alien species biomasses, fishing effort, and sea warming.

Fig. 1. Map of the study area, the extent of the coastal shelf of the Dodecanese islands within the Greek EEZ and the EU DCF DODEC area. The study area is subdivided in zones according to bathymetry and benthic habitat type.



Methodology

- The study area is the coastal shelf of the Dodecanese islands (Fig 1).
- The initial conditions for the Ecosim model were provided by the Ecopath model that was developed for the study area for the mid-2010s (2014 – 2016).
- Global prey variabilities of v = 2 for the native predators and v = 5 for the alien predators were used in the analyses[5].
- SST anomalies data according to the RCP 2.6, RCP 4.5, and RCP 8.5 global warming scenarios (AR5, IPCC) were downloaded from the Climate Change Atlas service of KNMI.
- SST data for the study ecosystem were downloaded from CMEMS.
- Environmental response functions data for temperature were downloaded from AquaMaps (native species) or adapted from the Ecosim model of the Israel coastal shelf[6] or the literature (alien species).
- We used Ecosim[7] to evaluate the effect of eight future scenarios for major stressors and combinations of these stressors in the study area (Table 1).

Table 1. Future scenarios list and associated stressor modes that were used in the model.

Scenario	Name	Alien species	Fisheries	SST rise
Scn1	RCP 2.6	Model predictions	Mid-2010s fishing effort	Best-case
Scn2	RCP 4.5	Model predictions	Mid-2010s fishing effort	Intermediate
Scn3	RCP 8.5	Model predictions	Mid-2010s fishing effort	Worst-case
Scn4	Fisheries (SB ban)	Model predictions	SB ban	Mid-2010s SST
Scn5	Fisheries (SSF reduction)	Model predictions	25% reduction in SSF fishing effort	Mid-2010s SST
Scn6	Cumulative (SB ban + SSF reduction + CC)	Model predictions	SB ban + 25% reduction in SSF fishing effort	RCP 4.5
Scn7	Cumulative (SB ban + SSF reduction + lionfish increase + CC)	Force (increase) biomass of lionfish x100	SB ban + 25% reduction in SSF fishing effort	RCP 4.5
Scn8	Cumulative (SB ban + SSF reduction + alien pufferfishes increase + CC)	Force (increase) biomass of alien pufferfishes x2	SB ban + 25% reduction in SSF fishing effort	RCP 4.5

Results and Discussion

- Under the worst-case IPCC AR5 scenario (RCP 8.5), the predicted impacts of sea warming on the ecosystem were considerable, as alien species were selectively favored and several native species experienced biomass reductions (Table 2).
- The reductions in forage and predatory fish biomasses and total catch under RCP 8.5 were not compensated by the predicted biomass increases of the alien species (Table 3).
- Trophic interactions (e.g., predation release, indirect trophic interactions) and differential responses of the species to the elevated sea temperatures were implicated in the forecasted ecosystem change.
- The effects of the simulated small-scale coastal fisheries fishing effort decrease resulted in benefits for several functional groups, despite parallel recoveries of many of their predators, underscoring the positive effects that reducing fisheries pressure may have on the state of the ecosystem (Tables 2 & 3).
- The results of the cumulative scenarios simulations highlighted that the effects of fishing effort decrease dominated over the impacts of moderate sea warming (RCP 4.5) or the forced biomass increases of lionfish or alien pufferfishes (Tables 2 & 3).
- A similar study[6] was published for the Israel coastal shelf ecosystem, which is experiencing more extreme conditions regarding all stressors considered here: There, future impacts of sea-warming and alien species biomass increases were predicted to be detrimental, whereas the positive effects of fishing effort decrease were dampened by the impacts of temperature and alien species biomass increases when acting together.
- Future availability of more comprehensive quantitative data regarding ecosystem components and local fisheries will allow the Ecosim model developed to be updated and adapted to support environmental and fisheries management in the area.

References

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Table 2. Changes in functional group biomasses in the Dodecanese islands coastal shelf ecosystem between the start (2017) and the end (2076) of the 60 yr period simulations. Changes are given as the ratio of the 2076 value to the 2017 value. Increases and decreases over 10% are highlighted in green and red, respectively. Increases and decreases over 50% are indicated with bold characters.

SCN/FG	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
Alien species vulnerability setting v = 5																																									
1	0.99	1.01	1.07	1.00	1.00	1.00	0.93	0.97	1.01	1.00	1.01	1.00	1.01	1.03	1.01	0.95	1.02	1.01	1.01	1.19	1.08	1.01	1.00	0.95	0.95	0.96	1.15	1.01	0.98	1.00	1.01	1.00	1.00	1.00	1.01	1.03	1.02	1.00	1.00	1.00	1.00
2	0.99	1.04	1.17	0.98	0.97	0.98	0.85	0.86	1.05	1.00	1.02	1.00	1.01	1.06	1.02	0.91	1.07	1.03	1.03	1.44	1.13	1.01	1.05	0.88	0.91	0.92	1.34	1.03	0.96	1.01	1.02	1.01	1.00	1.00	1.03	1.07	1.05	0.99	1.00	0.99	1.00
3	0.97	0.74	1.33	0.83	0.88	0.64	**0.35**	0.85	0.87	0.79	1.10	0.61	1.05	0.97	0.73	1.10	**2.15**	**0.36**	1.38	1.35	1.21	**1.86**	**1.62**	0.72	0.75	0.83	**2.30**	1.28	0.89	0.85	1.12	1.04	1.01	1.00	1.09	1.15	1.16	0.98	1.04	0.98	0.95
4	1.01	1.00	1.00	0.98	1.00	1.00	0.99	1.00	1.00	1.03	1.00	1.00	1.00	1.01	1.00	1.07	1.00	1.01	1.01	1.01	1.04	1.01	0.99	1.00	1.00	1.01	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98
5	1.10	1.30	1.00	0.92	1.10	0.94	1.10	1.17	1.02	0.96	0.96	0.95	1.20	1.04	1.06	**1.73**	0.84	0.90	1.14	**0.29**	1.23	1.15	0.63	0.99	1.02	1.28	0.84	1.00	0.93	0.98	0.98	0.99	1.00	1.01	1.00	1.00	0.99	1.00	0.98	1.00	0.93
6	1.10	1.35	1.16	0.88	1.07	0.92	0.94	1.06	1.08	0.99	0.98	0.95	1.21	1.11	1.08	**1.69**	0.89	0.95	1.18	0.68	1.41	1.16	0.67	0.87	0.93	1.20	1.18	1.03	0.89	0.99	1.00	1.00	1.00	1.00	1.02	1.07	1.04	0.99	0.98	0.99	0.91
7	1.10	1.35	1.16	0.88	1.07	0.92	0.94	1.06	1.07	0.98	0.98	0.95	1.21	1.11	1.08	**1.69**	0.89	**100.00**	1.18	0.68	1.41	1.16	0.66	0.87	0.93	1.20	1.18	1.03	0.89	0.99	1.00	1.00	1.00	1.00	1.02	1.07	1.04	0.99	0.98	0.99	0.91
8	1.06	1.14	1.14	0.92	0.94	0.93	0.94	1.02	1.09	1.12	0.97	0.99	1.29	1.12	1.07	**1.70**	0.67	0.94	**2.00**	0.74	1.45	1.25	0.63	0.87	0.92	1.20	1.14	0.92	0.91	0.97	1.01	1.00	0.99	0.98	1.03	1.06	1.05	0.99	0.98	0.99	0.95

Table 3. Changes in ecological indicators for the Dodecanese islands coastal shelf ecosystem between the start (2017) and the end (2076) of the 60 yr period simulations for the twelve future scenarios. Changes are given as the ratio of the 2076 value to the 2017 value. Increases and decreases over 10% are highlighted in green and red, respectively. Increases and decreases over 50% are indicated with bold characters.

	2017	2076							
Ecological indicators		Scn1	Scn2	Scn3	Scn4	Scn5	Scn6	Scn7	Scn8
Alien species vulnerability setting v = 5									
Total biomass (excluding detritus)	16.67	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Forage fish biomass	1.72	0.98	0.95	0.81	1.00	1.02	0.97	0.97	0.97
Invertebrate biomass	5.48	1.00	1.00	1.04	1.00	1.00	1.00	1.00	0.99
Predatory biomass	0.50	0.98	0.94	0.82	1.00	1.12	1.06	1.07	1.07
Alien fish to total fish biomass proportion	0.03	1.04	1.10	**1.65**	1.02	1.20	1.33	1.36	**1.67**
Kempton's Q index	3.29	1.00	1.01	1.05	1.00	0.97	0.98	1.02	0.97
Total catch	0.81	1.00	0.98	0.88	0.99	0.87	0.85	0.85	0.84
Mean trophic level of the catch (mTLc)	3.39	1.00	1.00	1.01	1.00	1.00	1.00	1.00	1.00
Mean trophic level of the community (mTLco)	1.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

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