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D4.3: Synthesis report on the comparison of WP3 and WP4 simulations:

Part 3 Invasive Species and Climate change

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Invasive species and Climate Change

Policy relevant summary

The impact of climate change on the susceptibility to invasion of marine ecosystem has been studied in 5 different basins: the Adriatic Sea, the Baltic Sea, the Barents Sea, the Black Sea and finally the North Sea. The focus of the study is to assess how climate change will alter the likelihood that a Non-Indigenous Species (NIS) of phytoplankton invading one of these European Seas and the potential impact on the community structure. Two scenarios are presented : the present day scenario (1980-2000) and the SRES-A1B scenario at the end of the century (2080-2100) except for the Barents Sea where the future scenario focuses on the middle of the 21st century (2046-2066).

The MSFD descriptors considered here are D1 – biodiversity and D2 – non-indigenous species.

The major findings are:

- Climate change can affect diversity of indigenous community, decreasing the species richness in the ecosystems with higher diversity.
- The likelihood of having a successful colonization of the ecosystem from a NIS does not significantly change with climate change. Nevertheless the model forecasts a potential change in the groups that are more likely to colonize the environment with consequences on community composition. These changes are site-specific.
- Nutrient concentrations play an important role in determining which functional group is more likely to successfully invade the ecosystem, hence any policy directed to manage nutrient concentration should include this driver in a complete cost-benefit analysis
- Impact of the NIS invasions on the community structure may increase under future climate as a consequence of the decrease in diversity of the indigenous community.

1. Introduction

Modelling Non indigenous Invasive Species (NIS) is a challenging task: many are indeed the drivers influencing the onset of the invasion and the conditions allowing the invasive species to colonize the new environment (e.g. is due to lack of predator? Or the NIS is a more efficient competitor for resources?). Furthermore the impacts of a successful invasion may also vary significantly affecting the habitat, the community or even the ecosystem functions.

For this reason, any estimates of how climate change and direct anthropogenic drivers influence the probability of having a successful invasion or modulate the impact of such invasion are affected by high uncertainty. To reduce this uncertainty, in MEECE we adopted an approach which allows us to assess the general susceptibility to NIS under climate change as described in D2.13.

2. Model description

The modified version of ERSEM (Blackford et al., 2004) described in MEECE D2.13 has been implemented in 5 European seas in order to study how climate changes can differently impact on susceptibility to invasion. This approach involves the modification of the biogeochemical model ERSEM to adapt the same framework to simulate invasion by NIS. Biogeochemical models are not able to simulate NIS as they are constructed using a framework based on Plankton Functional Types (PFT), an abstract concept whose characteristics are intended to mimic the functionalities of groups of marine plankton (e.g. Diatoms or Dinoflagellates). The parameters defining the different PFT's are usually set to represent the bulk properties of those groups, neglecting all variability inside the group. The onset of an invasion will clearly change the bulk properties but in an unpredictable way *a priori*. The rationale of this approach is to modify a standard biogeochemical model in order to enable it to simulate a large number of phytoplankton types (hereinafter called species) whose variability is similar to that observed in nature among species. With such a model it is possible to simulate the invasion of a NIS in the ecosystem, to evaluate its ability to settle in the new environment and to assess the impact of the settling in the community characterizing the ecosystem.

A 1D model (GOTM-ERSEM) has been set up for each basin in different locations (figure 1) in two time-slices: one representing present day condition (PD), and the other one (A1B) at the end of the century, except for Barents Sea where the focus is on 2046-2066. An ensemble of 100 elements has been run for each location, each one simulating a 40 years period. Invasion from a random NIS has been simulated every 5 years in order to let the system adjust to the NIS. The invasion is recorded as successful if after 3 years from the invasion the annual mean of the biomass of the NIS is above a threshold (7μgC/m^3). In this case the impact on community structure is assessed using the Bio-Pollution index for community structure (Olenin et al., 2007):

- **null** (BPL code: C0) if the average biomass in the fourth year is lower than 5% of the total biomass of the PFT
- **weak** (C1) if the average biomass in the fourth year is lower than 30% of the total biomass of the PFT
- **moderate** (C2) if the average biomass in the fourth year is lower than 50% of the total biomass of the PFT
- **strong** (C3) if the average biomass in the fourth year is higher than 50% of the total biomass of the PFT or the NIS is dominating the PFT

The outputs of the IPSL-CM4 model (Marti et al., 2006) has been used to derive the atmospheric forcing: data from the climate model have been extracted from the online repository (MEECE D1.2), linearly interpolated to derive the time series over the 5 different locations and finally used to derive the climatology needed by the 1D model.

In order to better constrain the physics, the temperature and salinity profiles simulated by the 1D model have been relaxed with a weekly time step to the vertical profiles simulated by the MEECE 3D regional models (MEECE D3.4, Table 1). These models also provided the initial condition for nutrient concentration in the two scenarios. As the BIMS-ECO model includes only one nutrient (nitrogen), initial condition of phosphorus and silicon have been calculated from nitrogen concentration assuming Redfield Ratio (N:P:Si = 16:1:16)

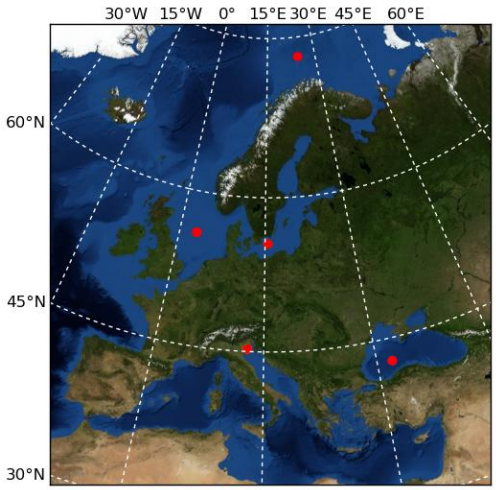

Figure 1: location of the five 1D models.

The 1D model also requires a background initial concentration of inorganic suspended particulate matter to simulate the light absorption due to non-living particles. For the southernmost basins (Adriatic Sea and Black Sea) this value has been calculated using satellite derived Inherent Optical Property (MEECE D1.1): the concentration of suspended particular matter has been assumed to match the light absorption coefficient due to detritus and yellow substances in winter, when biological activities are at minimum. For the three northern seas this approach was not possible because the satellite does not have adequate coverage of the area during winter, therefore information coming from the relevant regional models has been used.

The biological parameter set is identical in all basins, except for the range of the optimal temperature of indigenous species. This has been defined as equal to the range between minimum and maximum temperature simulated by the 3D models in the 5 locations (table 9.1). This assumption reflects the long-term adaptation of the community to local temperature. In the Barents Sea the range of maximum Chl:C ratio (Chl:C_{max}) and the initial slope of the P-I curve (α) have also been changed (shifted towards higher value of 50%) to account for the low light regime typical of high latitudes.

The parameter range for NIS has been assumed identical to the indigenous species of temperate case studies for all physiological parameters except for the optimal temperature: this has been set to a wide range (0ºC - 35ºC) in all domains in order to simulate invasion from NIS coming from different ecosystems, from cold waters to tropical.

Table 1: summary of the locations studied and range for optimal temperature used for the native species

Station	LAT	LON	3D model	Project partner	Range of Topt	
					PD [ºC]	A1B [ºC]
Adriatic	45.25N	12.77E	POM-BFM	UNIBO	10-30	12-32
Baltic Sea	55.5N	15.5E	ECOSMO	UiB	1-19	5-22
Barents Sea	73.23N	24.58E	NORWECOM	IMR	4-8	4-9**
Black Sea	42.83N	32.0E	POM-BIMS	IMS	6-23	10-30
North Sea	56.0N	3.0E	POLCOMS-ERSEM	NERC - PML	2-15	7-20

In order to assess the impacts of climate on the invasability of the system we consider the following metrics**:**

- Species richness: defined as total number of species surviving in the environment
- Probability of successful invasion: defined as the number of invasion where the NIS is able to settle in the environment relative to the total number of invasion simulated
- Bio-pollution index – community structure: ranging from 0 to 3, indicates an increasing level of disruption of the phytoplankton community

Table of linkages with MEECE deliverables

Deliverable	Comments
D1.1	Inherent Optical Property data
D1.2	Atmospheric forcing data
D1.4	Parameterisation of temperature range for NIS species
D2.12	Model implementation
D3.1	Outline of model scenarios
D3.4	Data from 3D simulations of climate response
D3.5	Atlas of marine ecosystem climate response

3. Glossary

In order to facilitate communication with other scientific communities, in particular biologists and biological oceanographers, the biogeochemical modelling community borrowed some terminology to describe the different components of the models. Sometimes this led to misunderstanding because the biological terms have a much deeper context and a lot more implication than those implied when used by modellers. It is therefore useful to explain how some of these terms will be used hereinafter.

SPECIES: it refers to one of the phytoplankton units in the model. As described in MEECE D2.13, the model has been tailored to describe some of the characteristics of single species (like specific range of thermal tolerance), but these abstract units are still far from the taxonomic definition of species. For this reason, the species richness results are low if compared to in-situ data.

DIATOMS: one of the four Plankton Functional Type (PFT) of the model. It describes large (>20μm) fast-growing macrophytoplankton that require silicon to grow. Mostly grazed by mesozooplankton.

FLAGELLATES: second PFT of the model, representing medium sized (2-20μm) nanophytoplankton mostly grazed by microzooplankton.

PICOPHYTOPLANKTON: this PFT depicts the smallest class (0.2-2μm) of phytoplankton, fast-growing, higher preference for ammonium compared to nitrate and mostly grazed by heterotrophic nanoflagellates.

DINOFLAGELLATES: the last PFT describes the large (>20μm) slow-growing phytoplankton, grazed almost exclusively by mesozooplankton. The modelled dinoflagellates are not parameterised to exhibit either mixotrophy or active movement.

4. Results

4.1 Climate change impact on ecosystem biodiversity

The biodiversity of the model system has been estimated as the ‘model’ species richness before any invasion is simulated. The model forecasts a gradient in species richness among the five seas (fig. 2): the Barents Sea is the less diverse, with 8.7 species coexisting on average in the 100 runs, followed by the Adriatic Sea (12.0 species), the Baltic Sea (14.9), the North Sea (16.4) and finally the Black Sea (17.0). This gradient is mostly dictated by the interspecific competition for resources, and in particular light and nutrients. For instance, in the Barents Sea only few species are able to exploit the low light characterizing this environment, while the high nutrient concentration in the North Sea is able to sustain a larger amount of species.

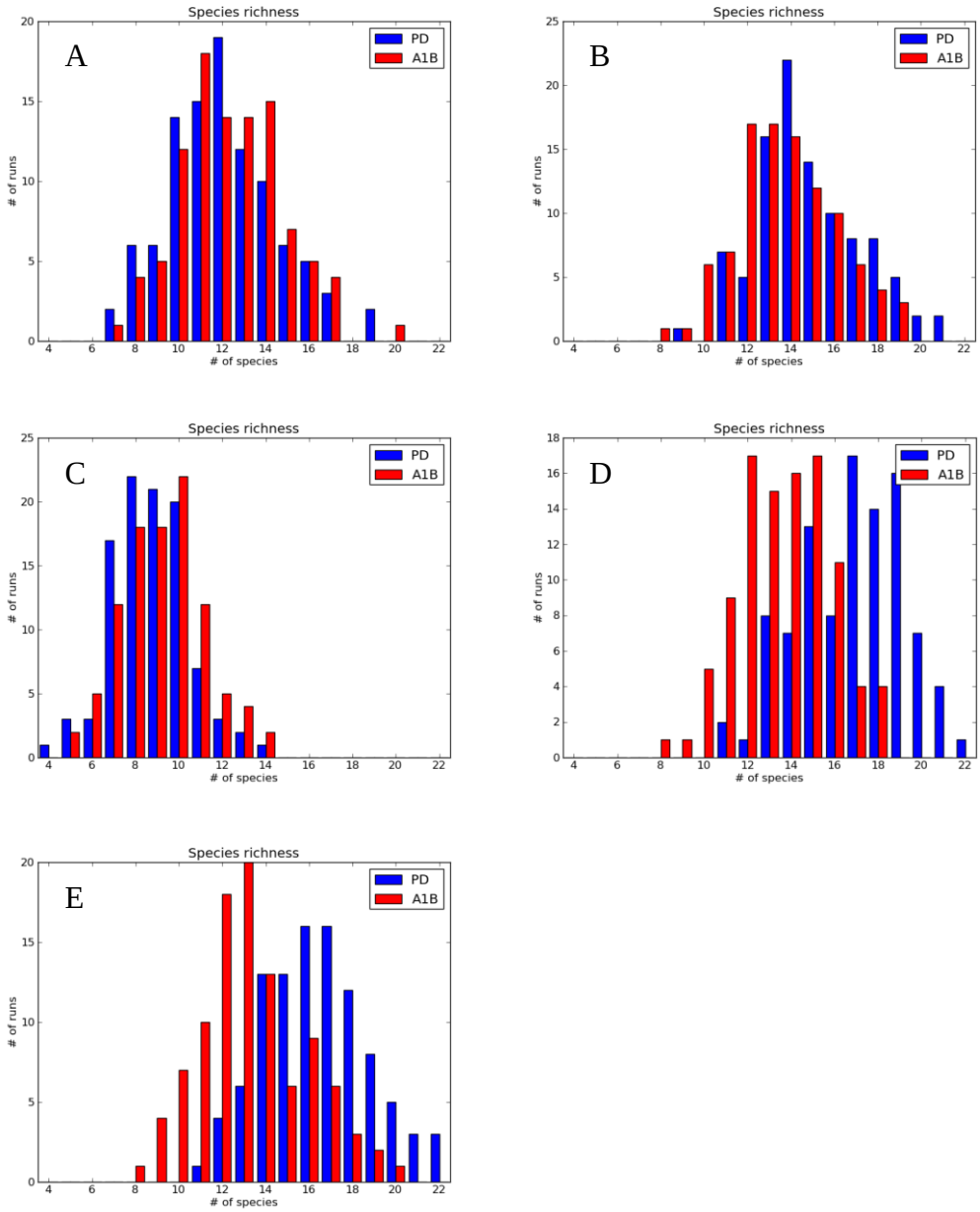

Figure 2: Distribution of species richness in all runs. Data are shown grouped for regional seas and scenarios (A: Adriatic Sea, B: Baltic Sea, C: Barents Sea, D: Black Sea, E: North Sea)

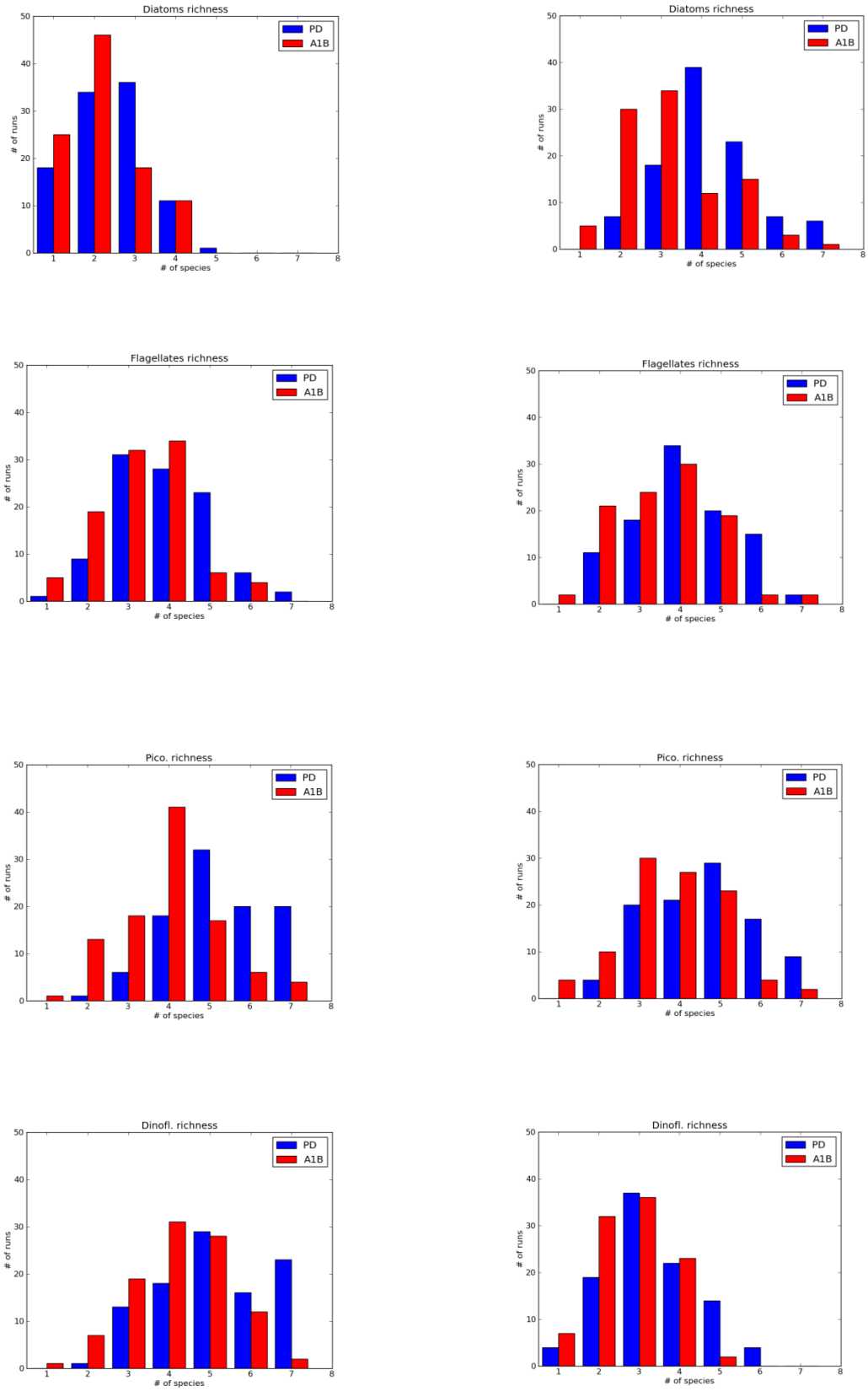

Figure 3: Species richness for each PFT in the Black Sea (on the left) and North Sea (on the right) in present day (PD) and future scenario (A1B)

The impact of climate change on the diversity of the indigenous community is generally low (fig. 2), and the distribution of species richness in the future scenario runs is almost identical for three of the basins (Adriatic, Baltic and Barents Seas). A clear decrease in the number of species is projected by the model in the Black Sea and the North Sea, although the distribution of species richness is not statistically separable for the one simulated under the present day scenario. Climate change does not impact the species richness of all PFT in the same way, but larger PFTs are more affected (diatoms in the North Sea, diatoms and dinoflagellates in the Black Sea – figure 3).

It is important to note that the absence of changes in diversity does not imply that the phytoplankton community will not be impacted by climate change. A previous implementation of the model in these regions showed that the species selected by the future environment have a higher optimal temperature, due to the increase in temperature of the water column. Here this shift has been imposed a priori because no transient 3D simulations (2000-2100) were available to provide adequate boundary conditions for the 1D model to simulate the long-term adaptation of the community to climate change.

4.2 Change in susceptibility to invasion from a NIS

In the present day scenario, the model estimates similar probability of success for invasion from a generic NIS in all European Seas, ranging between 16% and 20%, with the exception of the Barents Sea where only three NIS succeeded to colonize the ecosystems in the two scenarios simulated. This is due to the fact that the range in which the parameters of the NIS are randomly extracted is not tailored to the low light environment of this area.

Looking at the PFT to which the established NIS belong, a common pattern emerges in the four temperate seas: approximately 30% of the NIS belong to picophytoplankton, while the others belongs to the other three groups with similar proportion (20-25%), except in the Black Sea where only 13% of the non-indigenous diatoms have been able to colonize the system and more than 30% of dinoflagellates.

Climate change does not affect significantly the total probability of success of an invasion (about -2%) but it can change the likelihood of individual functional groups establishing themselves in the ecosystems (table 2). The model indicates that diatoms could become the group with higher probability of colonizing the Adriatic Sea ecosystem while in the Baltic Sea the picophytoplankton could increase its ability to settle in the ecosystem. Dinoflagellates are the group favoured in the North Sea and in the Black Sea, here together with diatoms. The causes driving all these changes are different from basin to basin, and it is not possible to derive common causes neither when the simulated changes are similar. For instance, the increase in probability of successful invasion from a diatom in the Black Sea can be correlated to the increase in the concentration of silicon in the future scenario (+90%), but the Adriatic Sea does not experience a similar increase in nutrient concentration.

All the invasive NIS show a similar pattern in the distribution of their optimal temperature (fig. 4) with a shift towards higher temperature. The magnitude of the shift is correlated with the increase in water temperature: where the increase in temperature is lower (Adriatic Sea, ~+2°C) the distributions of the optimal temperature of invasive NIS in the PD and A1B

scenarios overlap almost completely, while in the other cases there is a clear distinction, although the two distributions are not statistically separated.

Table 2: probability of colonization of the ecosystem by a NIS and PFT of the species. The total percentage is calculated relative to the total number of invasions (700 for each basin and scenario), while the others are calculated relative to the successful invasions.

		Total % of success…	… of which:			
Sea	sc.		Diatoms	Flagellates	Pico-	Dinoflagellates
Adriatic Sea	PD	15.9%	22.5%	21.7%	30.6%	25.2%
	A1B	13.4%	29.8%	21.3%	22.3%	26.6%
Baltic Sea	PD	17.3%	18.2%	24.0%	31.4%	26.4%
	A1B	15.0%	17.1%	21.0%	41.9%	20.0%
Barents Sea	PD	1.4%	0.0%	0.0%	0.0%	100.0%
	A1B	2.9%	0.0%	0.0%	0.0%	100.0%
Black Sea	PD	19.7%	13.0%	24.6%	29.7%	32.6%
	A1B	18.1%	20.0%	24.4%	18.1%	37.0%
North Sea	PD	16.1%	23.9%	25.7%	30.1%	20.4%
	A1B	13.1%	20.7%	23.9%	26.1%	29.3%

Table 3 summarizes the impact of the successful invasions on the phytoplankton community. As before, the Barents Sea is not comparable with the other basins due to its exceptional environmental condition. In the other seas, more than half of the invasion has null or weak impact in the present day scenario (Adriatic Sea 55%, Baltic Sea 61%, North Sea 67%, Black Sea 70%) while approximately 15% of the invasion are classified as moderate in all ecosystems. Finally more than 20% of the invasions have a strong impact on the community of the Adriatic and Baltic Seas, with the NIS becoming the dominant species in its PFT, while this occurs only in 18% of the cases in the North Sea and 13% in the Black Sea. In these two basins the model forecasts a substantial increase in moderate and strong impact invasion under future climate scenario, while the other two regions do not experience significant changes.

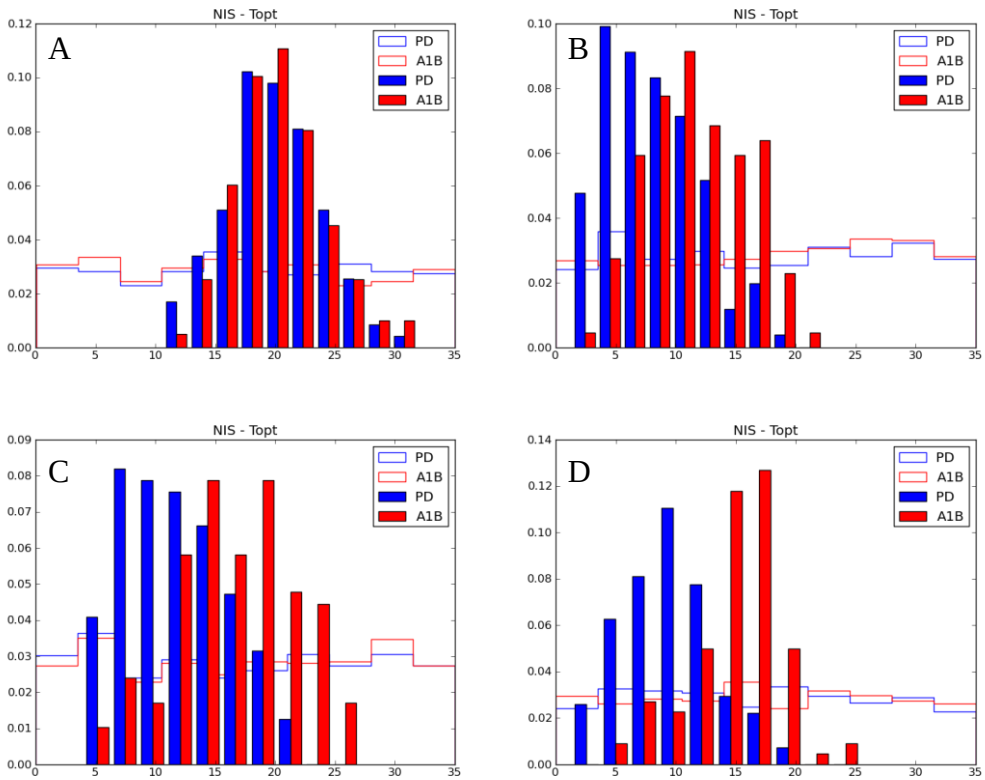

Figure 4: frequency distribution of the "Optimal temperature" parameter (on the x-axis in °C) of the NIS that successfully colonize the 4 temperate ecosystems (A: Adriatic Sea, B: Baltic Sea, C: Black Sea, D: North Sea). The two contour lines show the frequency distribution of all the NIS simulated. The frequency has been normalized in order to account for the different number of species that colonized the environment.

A clear pattern linking the estimated impacted of an invasion and the diversity of the indigenous community emerges: the North Sea and the Black Sea have been highlighted as the more diverse and these are also the less impacted by the NIS. Under future climate scenario, the model projects a significant reduction in diversity in these ecosystems (fig. 1) and at the same time an increase in the average impact of the invasion.

The PFT responsible for largest impact are different in the five basins studied and climate scenarios, but no clear pattern emerges (table 4)

Table 3: impact of successful invasion on the community classified using the BioPollution Level index.

	scenario	BPL=C0	BPL=C1	BPL=C2	BPL=C3
Adriatic Sea	PD	19.8%	35.1%	15.3%	29.7%
	A1B	17.0%	36.2%	21.3%	25.5%
Baltic Sea	PD	21.5%	39.7%	15.7%	23.1%
	A1B	20.0%	38.1%	19.0%	22.9%
Barents Sea	PD	0.0%	0.0%	0.0%	100.0%
	A1B	0.0%	0.0%	0.0%	100.0%
Black Sea	PD	25.4%	45.9%	15.9%	13.8%
	A1B	22.8%	33.1%	22.1%	22.1%
North Sea	PD	20.4%	46.9%	14.2%	18.6%
	A1B	18.4%	39.1%	18.5%	23.9%

Table 4: distribution of the PFT of NIS grouped on the basis of their impact on the community

		BPL=C0				BPL=C1			
	Scen.	Diatoms	Flagellates	Pico-	Dinofl.	Diatoms	Flagellates	Pico-	Dinofl.
Adriatic Sea	PD	36.4%	18.2%	27.3%	18.2%	20.5%	28.2%	35.9%	15.4%
	A1B	25.0%	31.3%	18.8%	25.0%	35.3%	17.7%	20.6%	17.7%
Baltic Sea	PD	19.2%	26.9%	38.5%	15.4%	14.6%	12.5%	37.5%	35.4%
	A1B	14.3%	9.5%	57.1%	19.1%	5.0%	20.0%	45.0%	30.0%
Barents Sea	PD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	A1B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Black Sea	PD	8.6%	31.4%	31.4%	28.6%	6.5%	24.2%	35.5%	33.9%
	A1B	6.9%	31.0%	24.1%	37.9%	11.9%	26.2%	23.8%	38.1%
North Sea	PD	17.4%	30.4%	30.4%	21.7%	26.4%	34.0%	28.3%	11.3%
	A1B	17.7%	35.3%	29.4%	17.7%	16.7%	27.8%	30.6%	25.0%
		BPL=C2				BPL=C3			
Adriatic Sea	PD	17.7%	29.4%	35.3%	16.7%	18.2%	12.1%	24.2%	45.5%
	A1B	35.0%	20.0%	20.0%	25.0%	20.8%	20.8%	29.2%	29.2%
Baltic Sea	PD	15.8%	26.3%	31.6%	26.3%	25.0%	39.3%	14.3%	21.4%
	A1B	25.0%	15.0%	55.0%	5.0%	33.3%	37.5%	12.5%	16.7%

Barents Sea	PD	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%
	A1B	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%
Black Sea	PD	18.2%	18.2%	27.3%	36.4%	36.8%	21.1%	10.5%	31.6%
	A1B	32.1%	21.4%	7.1%	39.3%	35.7%	17.9%	14.3%	32.1%
North Sea	PD	25.0%	6.3%	56.3%	12.5%	23.8%	14.3%	14.3%	47.6%
	A1B	29.4%	11.8%	0.4%	23.5%	22.7%	18.2%	9.1%	50.0%

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