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Effects of climate changes on the spatiotemporal dynamics of *Posidonia oceanica* in the Mediterranean Sea

PA103

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Environmental data

Posidonia oceanica **is the dominant seagrass in shallow waters of the Mediterranean Sea. Here, *P. oceanica* meadows cover between $2.5 \times 10^{10}\ m^2$ and $5.0 \times 10^{10}\ m^2$ of continental platform surface, where survive up to 45 m depth. *P. oceanica* forms underwater meadows supporting significatively the biodiversity in shoreline ecosystems. Indeed, it supports directly the biodiversity in marine ecosystems providing a habitat for several fish and invertebrate species, and at the same time it favours indirectly some terrestrial species, such as birds or animals living at the coastline, which take profit of the presence of this seagrass that represents the basis of their food web. *Posidonia oceanica*, is also considered an important carbon sink due to its capability to remove carbon dioxide from the biosphere.**

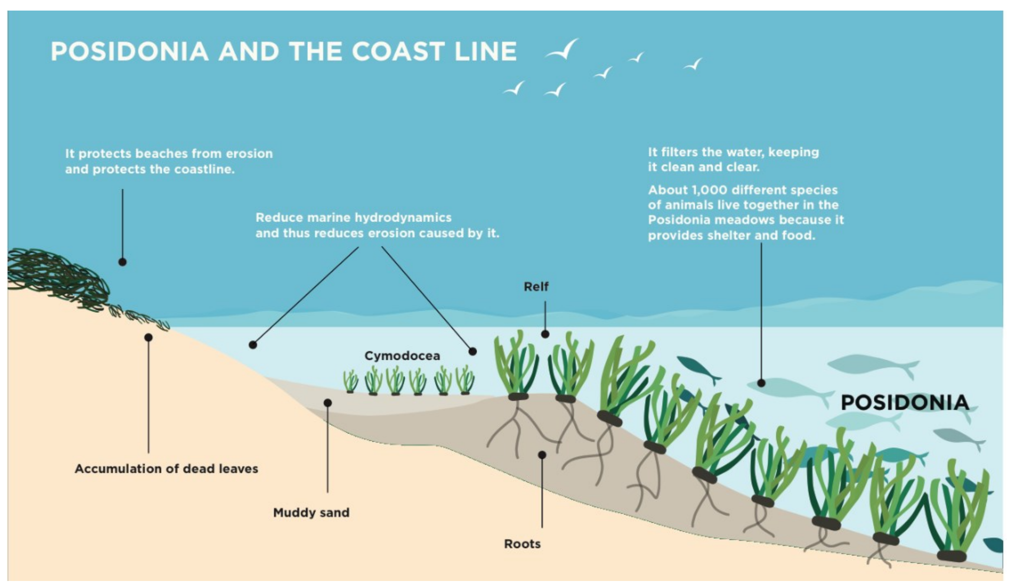

Fig. 1 – Scheme of the marine ecosystem of *P. oceanica* close to the shoreline (Courtesy of Santjosep.net).

The seawater temperature close to seabed plays a key role in the performance and survival of *P. oceanica*. In fact, the recent temperature enhancement due to global warming caused a significant increase of shoot mortality rates for this species. The recruitment rate of *P. oceanica* is strictly connected with the light intensity close to seabed, which depends on the incident solar radiation, the seawater turbidity and seabed depth. The health and conservation status of *P. oceanica* meadow is also affected by direct anthropogenic impacts, such as the high levels of eutrophication and turbidity recorded in coasts close to urban areas, caused by the great amounts of nutrients coming from human activities. On the whole, it has been estimated that the direct and indirect anthropogenic impacts caused in the Mediterranean Sea a loss up to 6.9% of *P. oceanica* meadows per year over the past 50 years, while the rate of loss was about 0.9% per year before 1940. For these reasons, in last years the behavior of *P. oceanica* density has been investigated also by using predictive models.

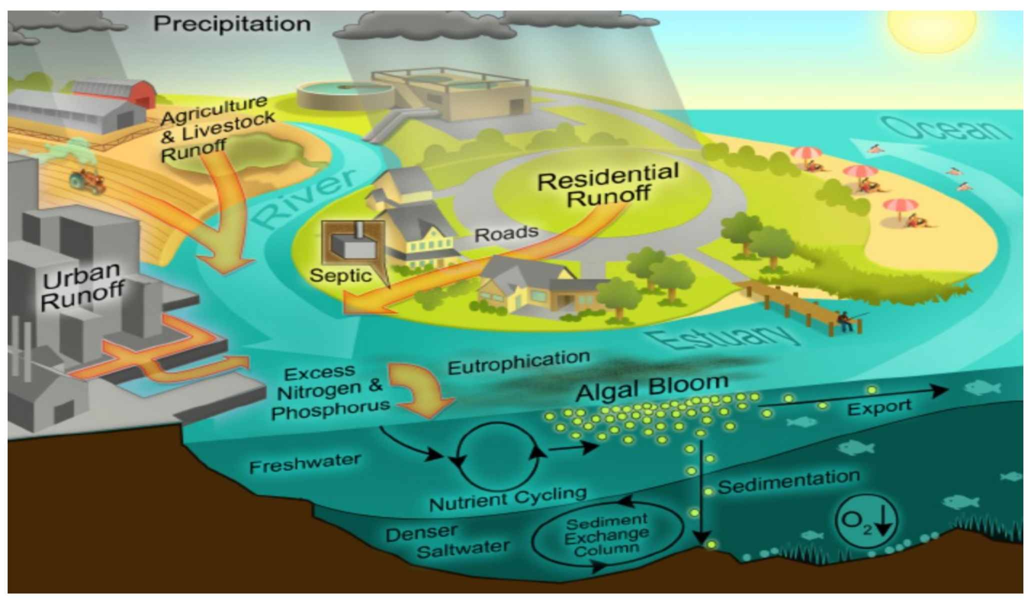

Fig. 2 – Scheme of anthropogenic activities impacting on the marine ecosystem of *P. oceanica* close to shoreline (Courtesy of University of North Carolina).

Geographical area

The study area is localized within the Capo Gallo – Isola delle Femmine Marine Protected Area (MPA) in the municipalities of Palermo and Isola delle Femmine. The area is characterized by a shallow and rocky coast with various orders of sea terraces alternating with high cliffs. The water matrix has been classified as "low stability" with an average value for the TRIX index of 1.78 which corresponds to a GOOD trophic status.

The present *P. oceanica* meadow has an average density of 326.39 $shoot/m^2$ and allows the prairie to be classified as in "equilibrium with normal density", according to the classification of Pergent. The lower limit of the meadow is located at a depth of 38 meters on a mixed, rocky and sandy substrate, and it is progressive. Here, the prairie is continuous and pure, with a cover of 50%, and a percentage of dead matte of 5%. The upper boundary of the meadow lies at variable depths ranging from a few metres to 0.4 m near the coast. This boundary, which is mostly clear, is mainly established on rocky substrate and is strongly influenced by the local hydrodynamics.

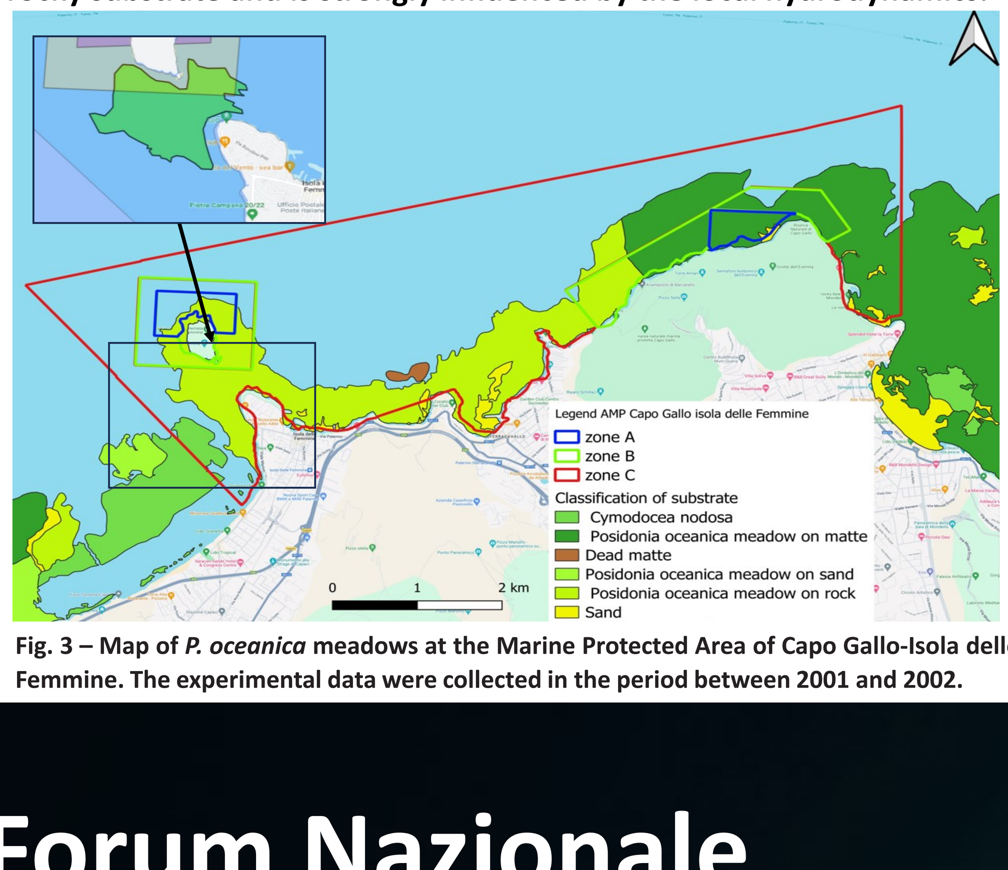

Fig. 3 – Map of *P. oceanica* meadows at the Marine Protected Area of Capo Gallo-Isola delle Femmine. The experimental data were collected in the period between 2001 and 2002.

The model

The model used to describe the dynamics of the density of *P. oceanica* in the Capo Gallo – Isola delle Femmine MPA, consists a simplified version of the advection-branching-death (ABD) model. The proposed model takes into account the main three physical processes involved in the clonal growth of seagrass meadow: the horinzontal growth of apex, the lifetime of shoots and apices, the new branches growth in other directions separated by a characteristic angle from the initial one.

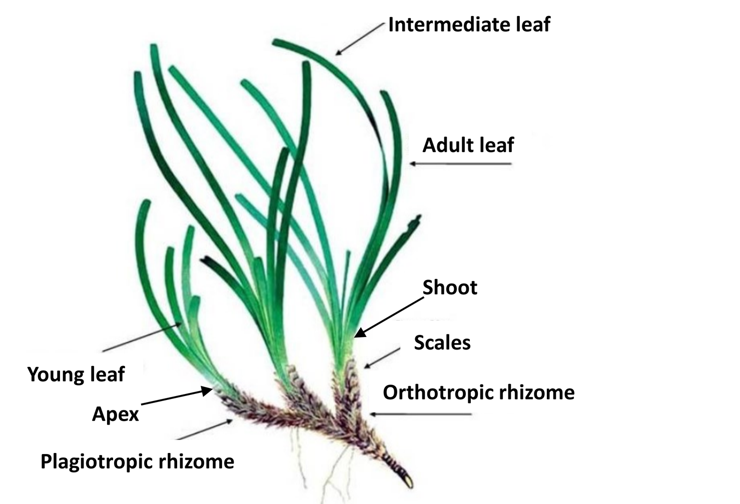

Fig. 4 – Description of the clonal growth mechanism for *P. oceanica* (Courtesy of Flagella, 2010).

The partial differential equation (PDE) which describes the spatiotemporal dynamics of *P. oceanica* density (n) in the Capo Gallo – Isola delle Femmine MPA is given by:

$$\frac{\partial n}{\partial t} = (\omega_b[z] - \omega_{d0}[DD])n - a(k - \omega_b[z])n^2 - bn^3$$
$$- \alpha n \nabla^2 n - \beta n \nabla^4 n + d_0 \nabla^2 n + d_1 \left\|\vec{\nabla} n\right\|^2$$

where the branching rate (ω_b) as a function of the depth (z), and the mortality rate (ω_{d0}) as a function of the annual cumulative temperature increase or degree-days (DD), are obtained as follows:

$$\omega_b\,[z] = 0.12 - 0.0031 \cdot z;\ \omega_{d0}[DD] = 0.071 + 0.001 \cdot DD(t).$$

Here, the degree-days ($DD(t)$) are considered as a function of time (t), since the model aims to reproduce the effects of a progressive temperature enhancement (up to 0.5 °C in the deepest layer of the water column) on the spatiotemporal dynamics of *P. oceanica* density.

Symbol	Interpretation	Unit	Value
ω_b	Branching rate (as a function of depth)	y^{-1}	$0.00 - 0.12$
ω_{d0}	Mortality rate (as a function of degree-days)	y^{-1}	$0.071 - 0.148$
a	Magnitude of local facilitative interactions	$cm^2 \cdot y^{-1}$	10-150
b	Magnitude of local competitive interactions	$cm^4 \cdot y^{-1}$	$10 - 100$
k	Strength of the non-local competitive interactions	y^{-1}	$0.03 - 0.06$
α	Magnitude of second order non-local facilitative/competitive interactions	$cm^4 \cdot y^{-1}$	$10^4 - 10^7$
β	Magnitude of fourth order non-local facilitative/competitive interactions	$cm^6 \cdot y^{-1}$	$10^6 - 10^{12}$
d_0	Diffusion coefficient for rhizome elongation	$cm^2 \cdot y^{-1}$	$10^2 - 10^3$
d_1	Spreading coefficient for rhizome branching	$cm^4 \cdot y^{-1}$	$10^3 - 10^4$
z	Depth of the water column	m	$0 - 38$
DD	Annual seawater temperature enhancement or degree-days (as a function of time)	$°C$	$0.0 - 76.5$

Table 1 – Biological and environmental parameters used in the simplified ABD model.

The parameter a controls the degree of bistability of the two homogenous solutions of the PDE, while the parameter b fixes the magnitude of the shoot density determing the saturation level for *P. oceanica* meadow. The parameters α and β fix the magnitude of the long-range non-linear competitive processes. The diffusion coefficient (d_0) and the spreading coefficient (d_1) are set equal to those calculated in condition the stationary front, using the biological parameters of *P. oceanica*.

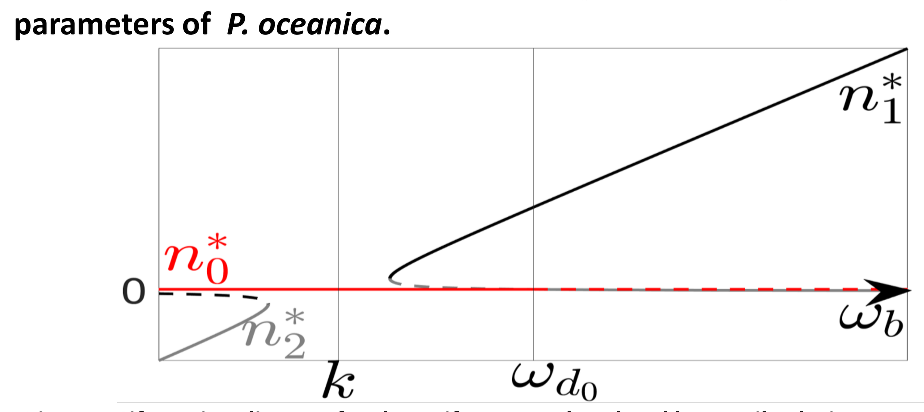

Fig. 5 – Bifurcation diagram for the uniform populated and bare soil solutions.

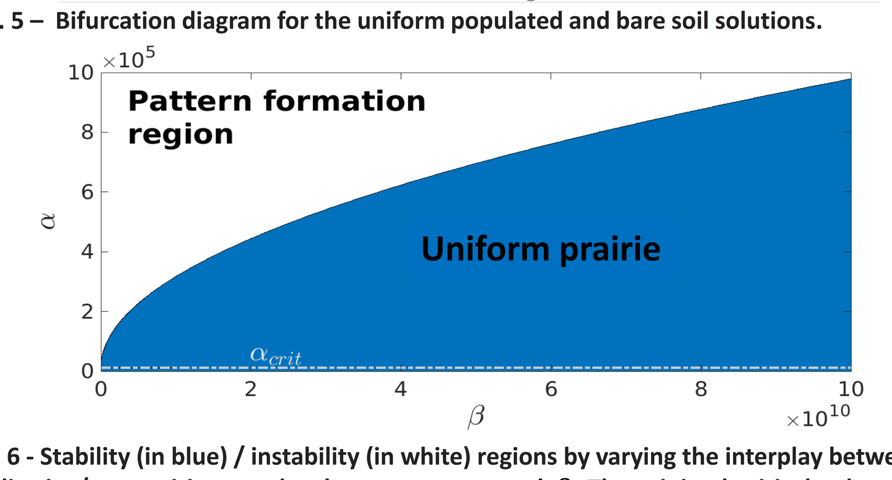

Fig. 6 - Stability (in blue) / instability (in white) regions by varying the interplay between the facilitative/competitive non-local parameters α and β. The minimal critical value for the parameter α depends on the kinetic parameters and the diffusion parameter d_0.

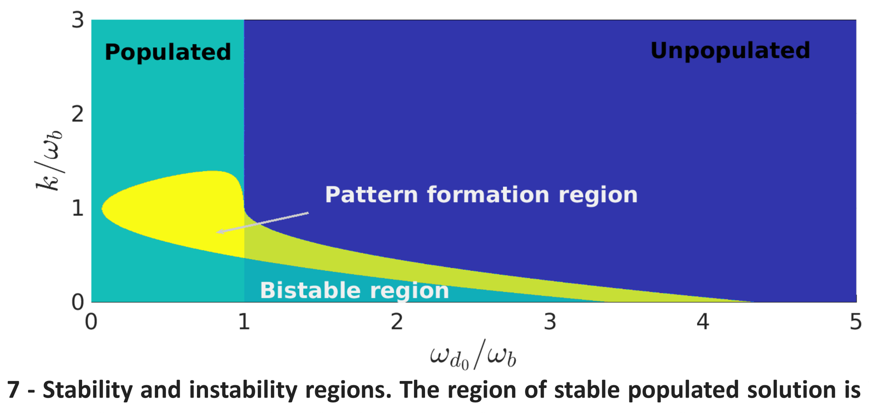

Fig. 7 - Stability and instability regions. The region of stable populated solution is in green, the region of stable unpopulated solution is in blue, the region of coexistence between the populated and unpopulated solutions is in light green, and finally the region where the populated solutions is unstable to patterns is in yellow.

Numerical simulations

Numerical simulations were conducted over a prairie patch with a bathymetric range of 0-38 meters, where Posidonia typically thrives. Initial condition is a uniform distribution with small random noise. The model parameters were designed to induce instability, leading to the formation of a fragmented prairie near the lower bathymetric limit over time. Numerical results for *P. oceanica* density indicate the seawater temperature increase could lead to desertification along with the presence of localized spots, specifically near the lower bathymetric limit.

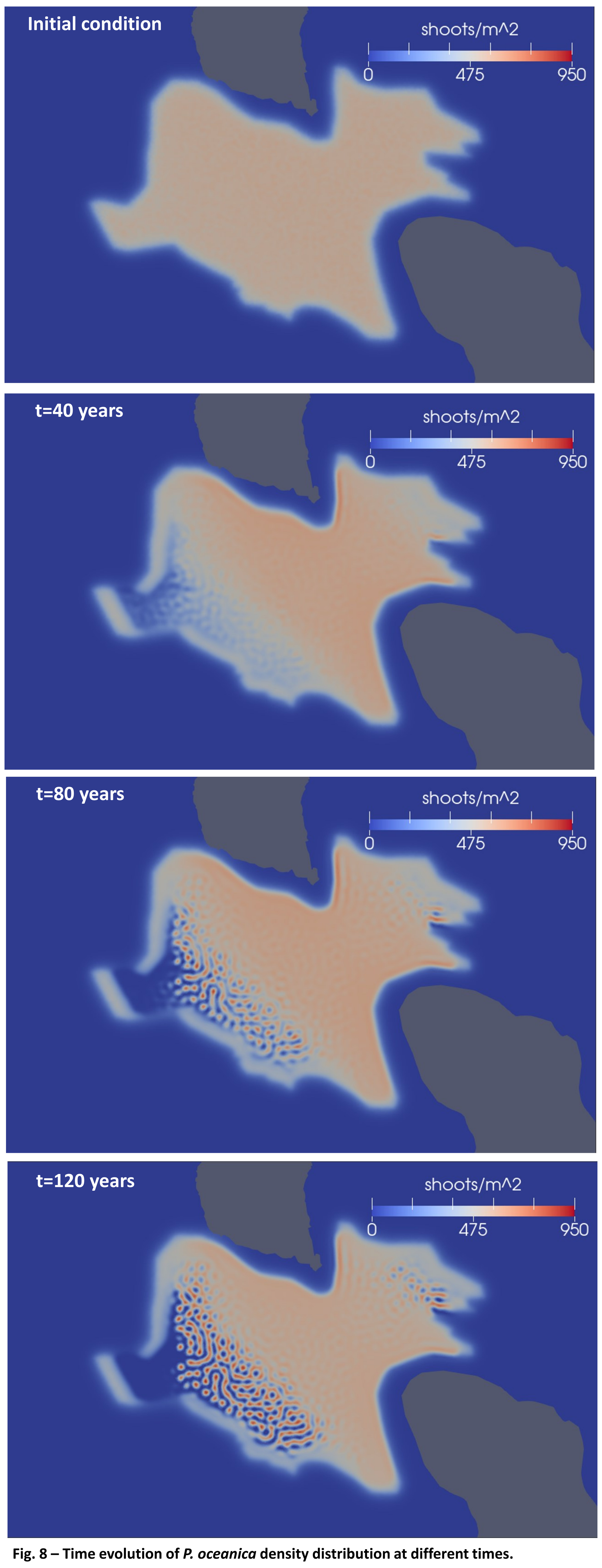

Fig. 8 – Time evolution of *P. oceanica* density distribution at different times.

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