DONOR AND RECIPIENT REGIONS FOR EXOTIC SPECIES OF MARINE MACROPHYTES: A CASE OF UNIDIRECTIONAL FLOW, THE MEDITERRANEAN SEA

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Abstract
The Mediterranean Sea is the recipient area for two major flows, at a world scale, of exotic macrophytes: (i) the Lessepsian pathway, based upon the Suez Canal, with the Red Sea as the donor area; (ii) the Japan pathway, based upon the transfer of molluscs. The flows in the opposite direction, stemming from the Mediterranean, are null or negligible, making this sea a kind of sink for species diversity.

Keywords: Phytobenthos, Algae, Mediterranean Sea, Biodiversity

An exotic species (= NIS, Non Indigenous Species), in a recipient area, is a species that has been transported by Man from a distant donor region (i.e. an area non-contiguous to the recipient area). Within exotic species, introduced species are species that can self-reproduce without human assistance (= established species, naturalized species). Within introduced species, invasive species are harmful species, either for other species and ecosystem functioning, the economy and/or human health. Within invasive species, transformer species are species that are autogenic ecosystem engineers and therefore build a new ecosystem, completely distinct from the native one [1-3]. The notion of 'biological invasions' encompasses the full range of these degrees. A biological invasion involves a donor area, a recipient area, a vector (e.g. a ship), a corridor (e.g. the pathway sailed by a ship) and of course a candidate species [3].

The Mediterranean is the area most impacted worldwide by biological invasions. ~1 000 exotic taxa have been recorded [4-7]. The main vectors are fouling and clinging on ship hulls, the species accompanying oyster culture, ballast waters, the aquarium trade and the Suez Canal [4, 7].

The flow of Red Sea species into the Mediterranean Sea, via the man-made Suez Canal ('Lessepsian migration'), is often considered as the major modern biogeographical event, at the Holocene scale [10]. Hundreds of Red Sea species, including 39 species of macrophytes (e.g. the Rhodobionta *Chondria pygmaea*, *Galaxaura rugosa* and *Hypnea anastomosans*, the Magnoliophyta *Halophila stipulacea*, the stramenopile *Stypopodium shimperi*), have entered the Mediterranean through this waterway since the 19th century [7,9]. Because of the recent enlargement of the Suez Canal, this flow is expected to dramatically intensify [10]. The flow is unidirectional. The migration in the opposite direction, i.e. from the Mediterranean to the Red Sea ('anti-Lessepsian migration'), is negligible, because of the mainly unidirectional water flow (Red Sea towards the Mediterranean) [8,9]. No Mediterranean macrophytes have been found to occur in the Red Sea.

Perhaps equivalent, in worldwide magnitude, is the flow of north-western Pacific macrophytes, from Japan, Korea and adjacent areas, towards other regions such as the North American Pacific, Australia, Atlantic European coasts and the Mediterranean Sea. This global bioinvasion event is due to the transfer of oysters (*Crassostrea gigas*, adults and spat) and Manila clams (*Ruditapes philippinarum*) from the north-western Pacific to other areas. The Mediterranean is probably the hardest-hit region worldwide. Between 40 and 50 species of macrophytes have been directly or indirectly (mainly via the North American Pacific coast and the north-eastern Atlantic coasts) introduced into the Mediterranean from the north-western Pacific Ocean. The most invasive species are *Sargassum muticum*, *Undaria pinnatifida* and *Codium fragile*. Their effect on native ecosystems is dramatic. Like the Red Sea-Mediterranean flow, the 'Japan path' is unidirectional: no seaweed species, or just a very few, have taken the opposite path.

The Mediterranean Sea can constitute a kind of 'hub' for Red Sea and 'Japanese' species. For instance, the Red Sea Magnoliophyta *Halophila stipulacea*, once introduced into the Mediterranean, was exported to the Caribbean Sea. The Japanese stramenopile *Undaria pinnatifida*, once introduced into the Mediterranean Thau Lagoon (southern France), has been exported to the north-eastern Atlantic Ocean (Brittany and Galicia).

Overall, the Mediterranean constitutes a sink for exotic marine macrophytes: incomings are massive, whereas outgoings are null or negligible. Could a similar mechanism, at the geological timescale, account for its very high species diversity, making the Mediterranean Sea the main hotspot worldwide for macrophytes species diversity?

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