Climate change and lessepsian migration: An example from the fish fauna of Cyprus

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Abstract: - This paper aims to give updated information on the lessepsian fish fauna of Cyprus. Specifically, an overview of the phenomenon of the lessepsian migration is given, together with a correlation of this phenomenon in relation to the mean annual temperature of the Mediterranean. Finally, the status of the lessepsian fish migrants in Cyprus is analysed, while some emerging information gaps are highlighted.

Key-Words: - Cyprus, lessepsian fish fauna, climate change

1 Introduction
In 1869, the Suez Canal was initiated and as a result a gradual organismic movement has been taking place thereafter. In spite of physical and hydrographical impediments, hundreds of Red Sea species crossed the canal and settled in the Mediterranean in a process termed ‘Lessepsian migration’. The name was given after Ferdinand Marie de Lesseps, the French diplomat and engineer who built the canal [1]. According to Por, this was ‘the most important biogeographic phenomenon witnessed in the contemporary oceans’ [2].

The opening of the Suez Canal has led to the joining of two biogeographical provinces. Thus, for over 140 years, Red Sea species, migrating through the canal, have been colonizing the Mediterranean. Marine species can migrate by several ways such as by adult migration, limited to mobile species; transport of planktonic larvae; rafting - the transference of organisms on drift logs, algae, pumice, and manmade objects; and by anthropogenic means, for example the deliberate introduction of species to transoceanic passage by fouling, boring, and ballast-dwelling organisms or the unintentional outcome of anthropogenic action [1].

The aim of this paper is to give updated information regarding the lessepsian fish species recorded from the coastal area of Cyprus, based predominantly on available literature.

2 Mediterranean Sea
The Mediterranean Sea is a semi-enclosed, deep (average depth 1.45 km, max. depth 5.5 km), oligotrophic basin with high density water production [3]. It communicates to the west with the Atlantic Ocean, to the Northeast with the Black Sea and to the southeast with the Red Sea. It is composed by two major interacting sub-basins, the Western and Eastern Mediterranean. The Mediterranean region is a climate transition area, tightly related to the global climate variability [3]. Over the last two decades there is growing scientific evidence which indicates various environmental changes, occurring with profound impacts on the Mediterranean basins and coasts. Because the European climate is under the influence of both subtropical and arctic regimes, the evolution of the physical parameters (i.e. temperature, salinity) in response to global warming is adjusting to the regional climate and circulation [3].

According to the same author [3], the prevailing multi-scaled circulation of the eastern Mediterranean Basin is dominated by strong currents and jets, as well as, by cyclonic/anticyclonic eddies and gyres. The eastern Mediterranean Sea has undergone major changes in circulation and water properties during the last twenty-three (23) years; it is not yet in a steady state and is potentially very sensitive to changes in atmospheric forcing. Sea-surface warming follows the warming of the Northern Hemisphere.

The main hydrographical characte-istics of the Levantine basin as it is today are its oligotrophy and the relatively high salinity and temperature values.
Summer surface temperatures reach a tropical 29°C with salinity high at 39.5 parts per thousand (ppt) [1].

On the other hand, the Gulf of Suez is a shallow body of water with salinity values as high as 45 ppt and wide temperature fluctuations. The length of the gulf, from its mouth at the Strait of Juba to its head at the city of Suez, is 314 km, and it varies in width from 19 to 32 km.

### 3 Global climate change and species distribution

Climatic change is known to affect many ecological properties interacting even with non-indigenous species (NIS) in many possible ways [4]. Direct effects on individuals and populations of altered physical–chemical conditions are distinguished from indirect effects on emergent properties (species distribution, diversity, and production). Climatically driven changes may affect both local dispersal mechanisms, due to the alteration of current patterns, and competitive interactions between NIS and native species, due to the onset of new thermal optima and/or different carbonate chemistry. As well as latitudinal range expansions of species correlated with changing temperature conditions, and effects on species richness and the correlated extinction of native species, some invasions may provoke multiple effects which involve overall ecosystem functioning (material flow between trophic groups, primary production, relative extent of organic material decomposition, extent of benthic-pelagic coupling).

Various studies have noted that lessepsian migrants are rapidly progressing westwards and northwards, through the whole eastern basin [5]. Although it is difficult to differentiate natural range expansion through time from climate-induced effects, particularly in regions lacking systematic field monitoring and temperature records, it seems that the last twenty years have seen an accelerated rate of westward migration of Lessepsian species [6]. Some strong examples for this statement are the one of the westward spreading of the rabbitfish *Siganus luridus* (Rüppell, 1829), recently reaching the Gulf of Lions [7] and this of the bluespotted cornetfish *Fistularia comersonii* Rüppell, 1838 recently reaching the French coast in the northwestern Mediterranean [8].

### 4 Lessepsian migration studies

Por [9] was the first who reviewed lessepsian migration and during his research he recorded 114 lessepsian species in the Mediterranean Sea and among them twenty-seven (27) fish species.

A couple of studies, conducted approximately forty years ago [11, 12], revealed the presence of thirteen (13) lessepsian fish migrants in Cyprus.

The first systematic effort to record the alien marine species of Cyprus was initiated in 1967 during a joint program (Biota of the Red Sea and eastern Mediterranean) by the Smithsonian Institution, the Hebrew University of Jerusalem, and the Sea Fisheries Research Station in Haifa. This project investigated the spread of the lessepsian migrants in the Levantine Basin (Egypt, Israel, Cyprus, Rhodes) and listed a total of 140 species known to have crossed the Suez Canal into the Mediterranean Sea [13].

More recently Golani [10] mentioned a total of 54 lessepsian fish species from the eastern Mediterranean, while he referred separately to the coasts of the islands of Cyprus and Crete which were characterized as special cases. The reason for this characterization was attributed to their peculiar geographic position and hydrographic conditions prevailing in these areas, which reflect the relatively low number of recorded lessepsian species.

In 2009 a list of the alien species (including lessepsian fish) of Cyprus was published [13], while further additions to the local lessepsian fish fauna were made a year later [14, 15].

### 5 The case of Cyprus

Cyprus is the third-largest island in the Mediterranean, situated in the eastern part of the basin and it is geographically the island closest to the Suez Canal.

The total production of marine fisheries for the year 2010 was estimated around 1369 tones [16]. According to the same source, aquaculture production for 2010 was estimated around 4077 tones (total income €20.1 million), from which 2260 tones were exported (€10.9 million income). The total production and exports of fishery products seem to have increased compared to 2009, reaching 3390 and 1685 tones respectively. In 2010 the value of aquaculture production ranged around €22.1 million in total.

Some species of lessepsian migrants are of economic importance in Cyprus and constitute in the total production of marine fisheries described above. *Siganus rivulatus* Forsskål, 1775 and S.
luridus are of significant commercial value in Cyprus. *S. rivulatus* is among the species which are being produced by local aquaculture, albeit in much smaller quantities [17]. Another example is the fish *Fistularia comersonii* which is commercially available in the market. Although this species is considered to be very tasty it has a relatively low commercial value.

On the other hand, some other lessepsian species, such as *Lagocephalus sceleratus* (Gmelin, 1789) have had adverse impacts on the local natural environment or/and humans. In Cyprus this species continues to have a significant negative impact on the artisanal fisheries, since it often damages both the fishing gear and the catch of the fishermen with its powerful jaws [16]. In some areas, many fishermen have even altered their fishing methods (gear, depths, time of the day, etc.) in order to avoid interaction with this species [13]. *L. sceleratus* possesses a potential risk to humans, since it contains tetrodotoxin, which may cause poisoning and even death.

The recently recorded lessepsian ichthyofauna of Cyprus comprises of twenty-six (26) lessepsian fish species [14, 15]. The most recent addition was that of *Scarus ghobban* [15] which has a wide distribution ranging from the eastern Pacific to the Red Sea and south to Algoa Bay in South Africa [15, 18].

Although Cyprus is situated very close to the Suez Canal (as previously mentioned) the number of the lessepsian species recorded to date, including those of fish, are lower in relation to those recorded from the other Levantine areas (Israel, Lebanon, Southern Turkey, Syria, Egypt) with the highest number of lessepsian fish (more than 70, until 2009) being recorded from the coasts of Israel [13, 19].

The relatively low number of lessepsian fish recorded from the coasts of Cyprus could be attributed partly to the location of Cyprus and its peculiar hydrographical conditions. The location of Cyprus (as in the case of Crete) is along the east-west gradient and for this reason there is a paucity of the distribution of lessepsian species [21]. This paucity may be explained by the cold temperature regime around these islands, a reduced continental shelf and the relatively large distance from the nearest shore, which is the main route of the advancing Lessepsian migrants [9].

On the other hand the lower number of lessepsian species recorded from Cyprus indicates a lack of relevant research [13, 19]. As previous studies demonstrated for lessepsian decapods [19] the low number of lessepsian species reported from Cyprus and the rather delayed start in their recording should be attributed to amongst other things, to the limited sampling effort that has been carried out in the area.

Additionally, the relatively low number of lessepsian species may be partly due to the insular character of Cyprus, since according to the theory of island biogeography amongst the factors that influence species richness on islands is their location relative to ocean currents [13]. As mentioned by the same authors [13], the general circulation in the Levantine Sea is described as a counter clockwise flow along the Libyo-Egyptian and Middle East slopes. The isolation of Cyprus, with a minimum distance of 70 km from the continent and the lack of a strong connecting current with the Levant coast, is a barrier for many species in successfully colonising the island. Therefore, transported by the current, marine species entering through the Suez Canal progressively advance along the coastline through Egypt, Israel, Lebanon, Syria, Turkey, and Greece. The colonization of Cyprus by those species may be hindered by water circulation.

### 6 Entrance rate of lessepsian fish

In respect to lessepsian fish species, it was recently shown that during the period 1869 to 2003, the entrance rate of lessepsian fish in the Mediterranean has been accelerating [21]. During the same period the cumulative species number of the lessepsian fish in the Mediterranean has been increasing by 0.71 species per year.

Similar results have also demonstrated that during the period 1910 to 2006, the entrance rate of the lessepsian fish has been increasing [22]. Specifically, during the 1990s the average number of new lessepsian fish entering the Mediterranean was 0.7 species per annum, while from 2000 onwards this number has increased to two species per annum. Additionally, in the same research, it was also demonstrated that for the period 1910 to 2006, there is a significant positive correlation between the number of newly reported lessepsian fish per decade and the increasing mean decadal temperature of Mediterranean waters.

In general, it seems that lessepsian species seem to be gradually expanding their distribution from Port Said both towards the west along the African coast, and towards the east along the coasts of Israel, Lebanon, and Syria, progressing from there, towards the southern Turkish coast and the coasts of Cyprus, and finally towards the Aegean Sea [21, 22].
7 Conclusions
The observed increase of the mean annual temperature of the Mediterranean waters could possibly explain the increasing rate of the entrance of the lessepsian migrants, including fish, in the Mediterranean. Additionally, the progressive geographical expansion of the previously known lessepsian species to greater latitudes in the Mediterranean could be explained by the same reason.

Thus, it is obvious that lessepsian migration is a continuous phenomenon and there is still a great gap of knowledge concerning lessepsian migrants species.

From the review of the available literature, it can be concluded that it is necessary to continuously monitor the relevant environmental parameters and the state of the natural environment for the better understanding of lessepsian migration mechanisms and pathways. Moreover, predictions of the future changes and the impacts of the non-indigenous organisms on the indigenous environment are essential.

Lessepsian migration is a complex phenomenon and it is related with the combined effects of the environmental parameters (e.g., temperature) and the biology of the species. Thus, it is necessary to study in depth the biology and ecology of lessepsian species for which - at least for a great number of them- there is significant knowledge gap. Acquiring this information one would interpret that it would be easier on one hand to predict the dispersion models of these species in the Mediterranean, and on the other hand their impact on the local natural environment and the indigenous populations.

The low number of reported lessepsian species from Cyprus is primarily attributed to lack of sampling in a wide range of habitats. Thus, well-organized and continuous samplings to record the distribution of the lessepsian marine species in the marine ecosystem of Cyprus will surely uncover many more species from all marine groups.

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