# THE TROPHIC AND FISHERY IMPACT OF INVASIVE *NEMIPTERUS RANDALLI* (RUSSELL, 1986) IN THE NORTHEASTERN MEDITERRANEAN SEA

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**THE TROPHIC AND FISHERY IMPACT OF INVASIVE NEMIPTERUS RANDALLI (RUSSELL, 1986) IN THE NORTHEASTERN MEDITERRANEAN SEA**

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# ABSTRACT

## THE TROPHIC AND FISHERY IMPACT OF INVASIVE NEMIPTERUS RANDALLI (RUSSELL, 1986) IN THE NORTHEASTERN MEDITERRANEAN SEA

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The Eastern Mediterranean Sea is one of the most invaded marine ecosystems under the impact of Lessepsian species which migrated from the Red Sea to the Mediterranean Sea after the construction of the Suez Canal. The impacts of Lessepsian species on the indigenous fish and fisheries can be both positive and negative. This study aimed to delineate the commonly seen Lessepsian species Randall's threadfin bream (*Nemipterus randalli*)'s impact on the food web and fishery dynamics besides current ecosystem health in Mersin, Levantine Sea using one of the most widely adopted marine food-web model, Ecopath with Ecosim. Synthetic ecological indicators were used to assess the ecosystem status of the study area. The model included thirteen functional groups that were related to *N. randalli* either by prey-predator interaction or competition. The model was parameterized using data collected by monthly bottom trawl samplings in 2019 and literature data. *N. randalli*'s stomach contents were analyzed. Scenarios were applied to compare *N. randalli*'s impacts on other species and fishery. The findings highlighted that *N. randalli*'s increasing population in the Eastern Mediterranean Sea negatively affected the commercially exploited native fish species: red mullet, surmullet, common pandora, and axillary seabream. Ecosystem of the study area showed common characteristics with other Eastern Mediterranean regions; however, it differed in ecosystem structure and functioning due to geographical differences. Considering the plans to expand further and deepen the Suez Canal in the near future, the increase in Lessepsian species necessitates the implementation of tailored conservation methods for the Eastern Mediterranean Sea. Targeted fisheries exploitation and incentives of marketing of *N. randalli* are alternative management strategies that can be recommended in the Eastern Mediterranean Sea to reduce the negative effects of the species.

Keywords: Eastern Mediterranean Sea, Lessepsian Migration, Suez Canal, Food Web, Ecopath with Ecosim

# ÖZ

## İSTİLACI NEMİPTERUS RANDALLİ (RUSSELL, 1986) TÜRÜNÜN KUZEYDOĞU AKDENİZ'DEKİ TROFİK VE BALIKÇILIK ETKİSİ

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Süveyş Kanalı'nın açılmasından sonra Kızıldeniz'den Akdeniz'e göç eden Lessepsian türlerinin de etkisiyle en çok istila edilen deniz ekosistemlerinden biri Doğu Akdeniz ekosistemidir.Lessepsiyen türlerin yerli türler ve ekosistem üzerindeki etkileri hem pozitif hem de negatif olabilir. Bu çalışmanın amacı; yaygın olarak görülen Lessepsian türü tel kuyruk mercan (*Nemipterus randalli*) balığının Mersin, Levanten Denizi'ndeki besin ağı ve balıkçılık dinamikleri üzerindeki etkisini ve mevcut ekosistem sağlığını en yaygın kabul edilen besin ağı modellerinden biri olan Ecopath with Ecosim kullanarak değerlendirmektir. Modelde *N. randalli* ile ilgili on üç fonksiyonel grup oluşturulmuştur. Model, 2019 yılında aylık dip trol örneklemeleri ile toplanan veriler ve literatür verileri kullanılarak modele uygun hale getirilmiştir. *N. randalli*'nin mide içeriği analiz edilmiştir. Ayrıca, *N. randalli*'nin diğer türler ve balıkçılık üzerindeki etkilerini karşılaştırmak için senaryolar uygulanmıştır. Bulgular, Doğu Akdeniz'de *N. randalli*'nin artan popülasyonunun, ticari olarak sömürülen yerli balık türleri, barbunya, tekir, kırma mercan ve yabani mercan balığını olumsuz etkilediğini gösterdi. Çalışma alanının ekosistemi diğer Doğu Akdeniz modelleri ile ortak özellikler gösterse de coğrafi farklılıkları nedeniyle ekosistem yapısı ve işleyişi bakımından farklılık göstermiştir. Yakın gelecekte

Süveyş Kanalı'nın daha da genişletilmesi ve derinleştirilmesine yönelik planlar da dikkate alındığında, Lessepsiyen türlerin artması Doğu Akdeniz için koruma yöntemlerini zorunlu kılmaktadır. *N. randalli*'nin olumsuz etkilerini azaltmak için Doğu Akdeniz'de tür odaklı balıkçılık ve türün pazarlanmasının teşvik edilmesi alternatif yönetim stratejileri olarak önerilebilir.

Anahtar Kelimeler: Doğu Akdeniz, Lessepsiyen Göçü, Süveyş Kanalı, Besin Ağı, Ecopath with Ecosim

**to those who always have time for a hug**

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# TABLE OF CONTENTS

CHAPTERS

APPENDICES

# LIST OF TABLES

TABLES

# LIST OF FIGURES

FIGURES

# LIST OF ABBREVIATIONS

| | |
|---|---|
| EwE | Ecopath with Ecosim |
| B | Biomass |
| Q/B | Consumption Biomass |
| EE | Ecotrophic Efficiency |
| TL | Trophic Level |
| MTI | Mixed Trophic Impact |
| KS | Keystoneness |

# CHAPTER 1

# INTRODUCTION

Marine ecosystems are hugely impacted by various stressors including climate change, biological invasion, pollution, nutrient enrichment, shipping, habitat destruction, and overfishing (Halpern et al., 2015; Costello et al., 2010). The Mediterranean Sea is under the threat of these multiple stressors (Coll et al., 2010; Tsikliras et al., 2013). The Mediterranean Sea is a semi-enclosed basin extending from 30° N to 45° N and from 6° W to 36° E and is considered oligotrophic due to significant phosphorus limitation (Krom et al., 1991; Thingstad et al., 2005) and limited flows of external sources such as riverine and Atlantic flows (Bethoux et al., 1992).The Levantine Basin part of the Mediterrenean Sea is surrounded by the coasts of Turkey, Syria, Lebanon, Israel, Egypt, Cyprus, and the Crete Island (Fig. 1.1). It is connected to the Red Sea through, an artificial sea-level waterway, the Suez Canal (Fig. 1.1).

The Levantine Sea is considered the most invaded marine ecoregion in the world, with a ratio of alien to native species richness of 0.69 (Katsanevakis et al., 2014). It has been tremendously affected by two human-induced effects: the constructions of the Suez Canal and the Aswan Dam. Both have a crucial role in the species migration from the Red Sea to the Mediterranean Sea, known as the Lessepsian migration (named after the engineer and developer of the canal Ferdinand de Lesseps) or Erythrean invasion.

The Suez Canal was built in 1869 to provide a shorter maritime route between the western Pacific, Indian Ocean and the Mediterranean, the Atlantic Ocean. In the beginning, Suez Canal was about 8-meter-deep. Towards the end of 1920, the depth was increased to 11 m (Steinitz 1927; Norman 1927, 1929). Then, its depth changed to 14.0m in 1956, 19.5 m in 1980, 22.5 m in 2001, and most recently to 24 m in 2010 (Suez Canal Authority, 2021). Increasing the depth of the Suez Canal facilitated the migration of species to the Mediterranean Sea from the Red Sea (Öztürk, 2010).

Constructed in the 1960s, the Aswan Dam limited the outflow of the Nile River, which acted as a natural hydrological barrier. Aswan Dam reduced nutrient-rich silt water from the Nile into the Eastern Mediterranean and increased salinity in the Levantine Sea (Oren, 1969), causing Red Sea-like environmental conditions in Eastern Mediterranean (Zakaria, 2015). It accelerated the migration of species fro m the Red Sea.

With impacts of these two constructions, the abundance and biomass of invasive fish species have doubled during the last two decades in the Levantine Basin (Edelist et al., 2013). One of the reasons for this is that the environmental conditions in the Levantine Sea are similar to that of tropical and subtropical regions. This also facilitated the successful establishment of the invasive species from the Red Sea (Bilecenoğlu, 2016). Another reason is that the Red Sea is generally poorer in terms of nutrient and it is saltier (38.7 psu in the Levantine Sea, 40–41 psu in the northern Red Sea and around 41 psu in the Gulf of Suez) than the Mediterranean Sea, holding an advantage for Red Sea species over Mediterranean species for their wide range of environmental tolerance (Zakaria, 2015).

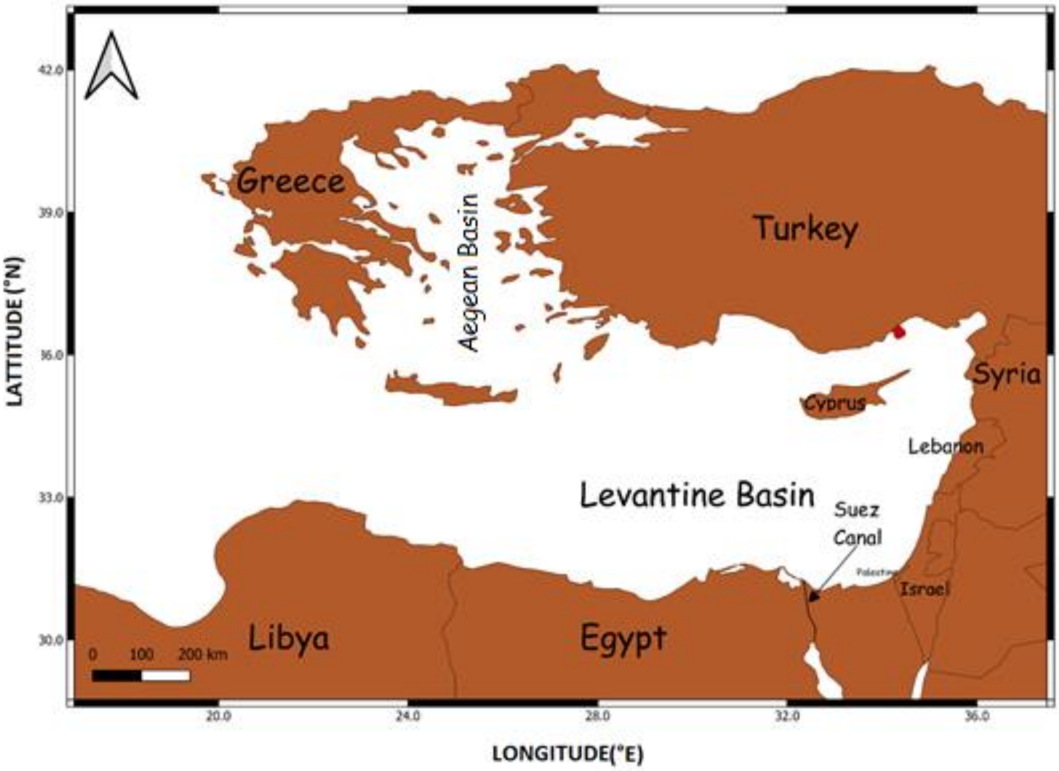


Figure 1.1. Levantine basin map (drawn with QGIS 3.20)

Lessepsian species have ecological and economic impacts on the Eastern Mediterranean Sea and some may even pose health hazards to human. Some edible species such as swimming crab (*Portunus segnis)*, green tiger prawn (*Penaus semisulcatus)*, Randall's threadfin bream (*Nemipterus randalli*) and *Sphyraena* spp. take part in the fish market as a positive impact on the economy, whereas species like striped eel catfish (*Plotosus lineatus*) silver-cheeked toadfish (*Lagocephalus sceleratus*) and nomad jellyfish (*Rhopilema nomadica*) pose health hazards, damage fishing nets and hamper recreational activities, respectively (Çinar et al., 2021; Lefkaditou et al., 2011).

Tillier (1902) reported Red Sea hardyhead silverside (*Atherinomorus forskalii*) being the first fish that entered the Mediterranean Sea from the Red Sea. However, the exact date was unknown. Tillier (1902) and Norman (1929) suggested that this fish reached the Mediterranean earlier than 1902. When the Canal deepened to 11 meters in the late 1920s, other Lessepsian species were reported on the Israeli and Egyptian Mediterranean coasts (Steinitz 1927; Norman 1927, 1929). The number of Lessepsian species is still increasing (Arnd et al., 2015). Çinar et al. (2021) reported that 65 Lessepsian species were observed along the Turkish coasts. %58 of alien marine species in Turkey were from the Red Sea. One of the common Lessepsian species observed on the Turkish coasts is *Nemipterus randalli*. It has recently become abundant in the catch composition (Yemisken et al., 2014) and a commercially important fish species in Turkey.

*N. randalli* was first reported in Haifa Bay, Eastern Mediterranean Sea, in 2005. However, Golani and Sonin (2006) misidentified *Nemipterus randalli* as *Nemipterus japonicus*. After comparison with other specimens in the area, the authors accepted the misidentification. Similarly, Lelli (2008) confirmed the existence of *N. randalli* on the Lebanon coast in 2007. *Nemipterus randalli* was caught for the first time in Turkey in İskenderun Bay in 2007 at a depth of 50 m (Bilecenoğlu & Russell,2008). Then, it was captured at 10-15 depths in Gökova Bay in the southeastern Aegean Sea in 2011 (Gülşahin & Kara,2013). *N. randalli* was also reported in "New Mediterranean Marine Biodiversity Records" in the Aegean Sea in 2013 (Bilecenoğlu et al.,2013). By 2016, it was caught around İzmir Bay (Aydın & Akyol,2017), showing that the species had been spreading in the Mediterranean Sea over the years.

## 1.1 Randall’s Threadfin Bream (*Nemipterus randalli*)

Figure 1.2 *Nemipterus randalli* (frozen)

The family of *Nemipterus randalli*, Nemipteridae, includes five genera with 62 species (Russell,1990) under the order of Perciformes. They are widespread in the tropical and subtropical Indo-West Pacific region and, conversely, they do not live in the eastern Pacific and Atlantic Oceans (Russell, 1990). It is distributed starting from the Gulf of Aden, East African coast, Seychelles, and Madagascar to the western Indian region, Pakistan coast, the Persian Gulf, and the Red Sea, including the Gulf of Aqaba (Baranes & Golani, 1993). *Nemipterus randalli* is a demersal fish living in sandy or muddy bottoms with a depth of 22-225m (Russell, 1986).

*Nemipterus randalli* has an ellipsoid body shape. It has a silvery pink color with 3 or 4 faint yellow stripes. It can be distinguished by its forked caudal fin, whose upper rays having a long trailing filament (Russel, 1990). In the Arabian Sea, its maximum length is 25 cm (Kalhoro et al., 2017), and the common length is about 15 cm (Russel, 1990).

Its mean length at sexual maturity is 11 cm, and gonad maturity begins to increase in February and reaches its maximum in April and May in Iskenderun Bay (Demirci et al., 2018). Yapıcı and Filiz (2019) showed that its breeding season is between

April and October in Gokova Bay. Özen (2021) also showed that its breeding season is between May and October in Antalya Bay. *N. randalli* is a batch spawner that sheds eggs more than once during the spawning season. This strategy was known for increasing its adaptation to difficult conditions by balancing fitness costs (Wootton,1998). The diet of *Nemipterus randalli* includes polychaetes, crustacea, (especially Natantia and Brachyura), molluscs and fish (Yapıcı & Filiz,2019; Gurlek et al., 2010). However, these studies did not give detailed information about the fish species.

Yemisken et al. (2014) reported in their study that from May 2010 to January 2011 the frequency of *N. randalli's* occurrence in trawl was 100% in the İskenderun Bay. Moreover the fisheries catch was composed of 11.3% commercial Lessepsian species in the area. *N. randalli* has been exploited by trawl fisheries in Turkey as local markets started to sell it as common pandora (*Pagellus erythrinus*) (Yapıcı & Filiz, 2019). High similarity of *N. randalli* to *Pagellus erythinus* led local fishers to mistakenly name this species as *Pagellus erythinus* (Avşar et al.,2016). Edelist et al. (2013) showed that invasive *N. randalli* displaced native *Pagellus erythrinus* on the Israeli coast as it spread in the Eastern Mediterranean. According to the Ministry of Agriculture & Rural Development of Israel, the total catch by Israel's fisheries were 4,280 t in 2010 (Edelist et al., 2013). While the catches of *Pagellus erythrinus* were 34 and 26 tons in 2009 and 2010, the catches of *N. randalli* were 34 and 26 tons in 2009 and 2010. Also, the catches of *N. randalli* were 126 and 147 tons respectively in these years. The data showed that *N. randalli* has become an important species in the region by displacing indigenous species such as *Pagellus erythrinus* and has constituted a significant amount of demersal catches compared to the other native commercially important ones. Uyan et al. (2016) and Bilge et al. (2019) defined *N. randalli* as a species with a high potentiality of being invasive in the Mediterranean by the Aquatic Species Invasiveness Screening Kit. This tool incorporates minimum requirements for assessing the target organism's biological, ecological and biogeographical information.

Despite the increasing prominence of *N. randalli* in the commercial fisheries catches, Turkey does not have fishery statistics for *N. randalli.* This species is recorded as common Pandora (*Pagellus erythrinus*) in the official statistics of Turkey (TUIK,2019). Therefore, it is critical to delineate the impact of *N. randalli* in the food web of the Levantine Sea and explore possible mitigation strategies considering its negative interactions with the indigenous commercially important species.

## 1.2 Food Web Modelling

One of the most widely adopted methods to understand the impacts of introduced species on ecosystems is ecological modeling. Trophodynamic (food web) models are invaluable tools to show food web interactions between species. The most common and user-friendly marine food web modeling program is Ecopath with Ecosim (Christensen & Walters,2004). Ecopath with Ecosim models were used to delineate the functions and structures of marine ecosystems. They were also used to assess environmental changes and anthropogenic effects and to explore fishing management policy alternatives (Coll et al., 2009; Piroddi et al., 2010; Heymans et al., 2012).

Limited modeling studies were conducted to represent the food web in the Eastern Mediterranean Sea. Papapanagiotou et al. (2020) and Tsagarakis et al. (2010) demonstrated the trophodynamic relationships in the North Aegean Sea. Some other studies investigated the alien species and their impacts on the fish communities in the Gulf of Mersin (Saygu,2020), and investigated the impacts of Lessepsian species in Cyprus (Michailidis et al.,2019) and Israeli (Corrales et al.,2017) coasts. However, the interactions of Lessepsian species with indigeneous species in terms of trophodynamics and their implications on fisheries are yet to be investigated. This study aimed to delineate the impact of one of the most common invasive species, *N. randalli* in Erdemli, Mersin, Levantine Basin and evaluate possible mitigation strategies against its adverse effects to establish an exemplary study that could be extrapolated to similar cases in other regions in the Mediterranean Sea.

## 1.3 The Aim of Study

This study is the first study to focus only on the impact of Lessepsian species, *Nemipterus randalli* on the Northeastern Mediterranean Sea food web and to identify the vulnerable native species that could be negatively affected by the successful establishment of this species. The reason to choose *N. randalli* as a target species in this study is its dramatic increase in population in the Northeastern Mediterranean Sea, its commercial value for fisheries and literature gaps about *N. randalli*.

This study aims to answer three questions;

i) What is *N. randalli's* impact on the indigenous species in the Northeastern Mediterranean Sea food web?

ii) How does *N. randalli* affect the fishery dynamics in the Northeastern Mediterranean Sea?

iii) How would the *N. randalli's* impact change under commercial fishery and decreasing population scenarios, and what management strategies can be applied for mitigating its impacts?

# CHAPTER 2

# MATERIALS AND METHODS

## 2.1 Study Site and Sampling

The study site covered 1.76 $km^2$ of Erdemli, Mersin, in the northeastern Levantine Basin and was located between 36°25'10.9"N -34°20'23.9"E and 36°34'02.5"N - 34°18'14.1"E. Fish samples were collected monthly with 18 mm trawl nets at the depths from 16m to 230 m with three depth strata around 50m, 120m, and 210m from January 2019 to January 2020. Data was collected from 68 stations. Trawling sampling times were 15 minutes at the shallowest stations, 60 minutes at the deepest stations and 30 minutes at the mid-depth stations. The study site is depicted in Figure 2.1.

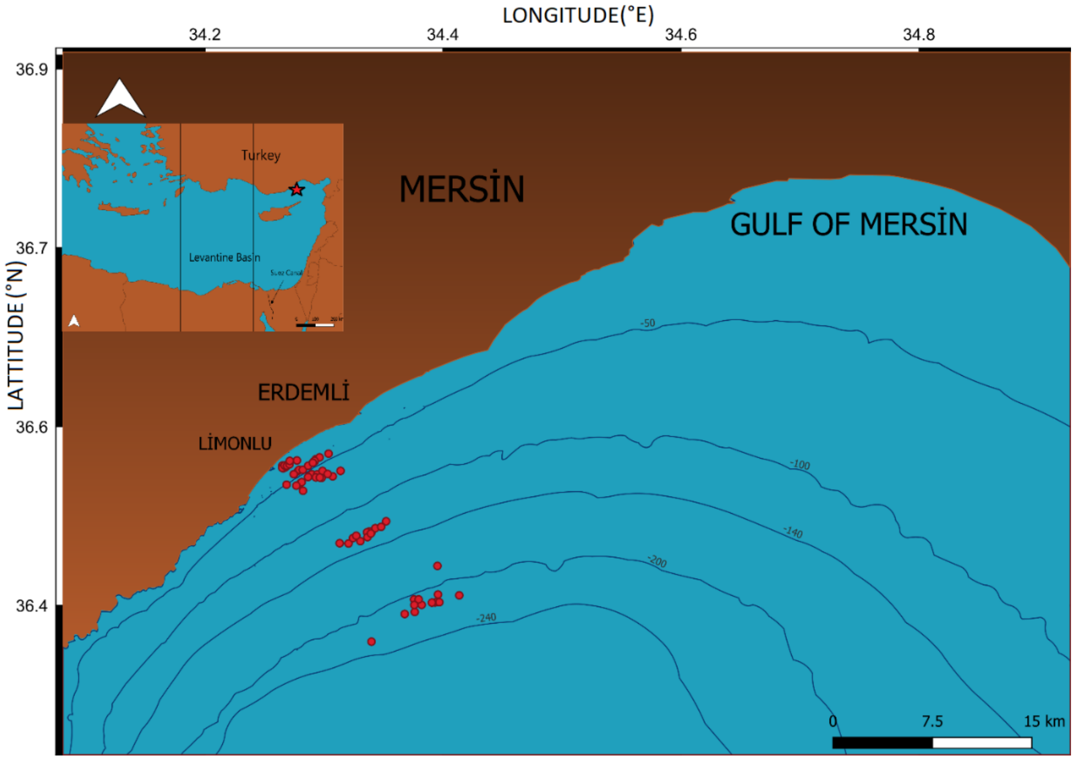


Figure 2.1 Modelled area which includes trawl sampling coordinates located off Erdemli, Mersin (Eastern Mediterranean)

## 2.2 Laboratory Studies

At the laboratory, lengths of *Nemipterus randalli*'s samples were measured. Since there is a filament at the upper tail end of *N. randalli*, fork length was used for length measurements as suggested in the literature. *Nemipterus randalli's* stomach samples were weighed and stored in the freezer for stomach content analysis. Since there is a filament at the upper tail end of *N. randalli*, fork length was used for length measurements as suggested in the literature.

Stomach samples were chosen from the species length list by considering at least three samples from each cm length and a total of 16 length classes between 6 cm to

21 cm to prevent underrepresentation of certain length classes.

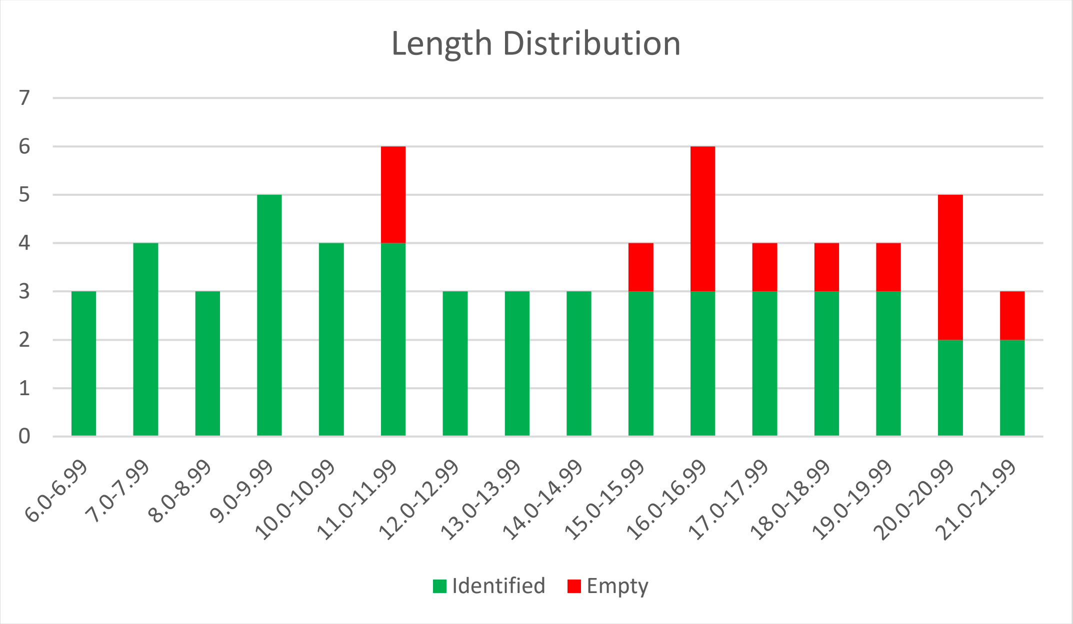


Figure 2.2 Length distribution of the samples (x axis implies sample number, y axis implies length of samples, green color indicates identified stomachs, and red color indicates empty stomachs in cm)

Table 2.1 Seasonal distribution of individuals whose stomach samples were analyzed according to their length

| **Spring(cm)** | | **Summer(cm)** | | **Autumn(cm)** | | **Winter(cm)** | |
|---|---|---|---|---|---|---|---|
| 8.5 | 16.7 | 9.5 | 15.5 | 6.0 | 15.8 | 6.3 | 15.7 |
| 9.0 | 18.5 | 9.6 | 16.2 | 6.6 | 17.8 | 7.4 | 16.6 |
| 9.5 | 19.3 | 9.8 | 17.5 | 7.8 | | 7.6 | 18.0 |
| 10.1 | 20.3 | 10.0 | 17.9 | 7.8 | | 8.6 | 18.8 |
| 10.6 | 20.5 | 10.3 | 19.0 | 8.3 | | 11.5 | 19.2 |
| 11.6 | 21.0 | 11.4 | | 13.6 | | 11.9 | |
| 13.8 | 21.1 | 12.5 | | 14.3 | | 12.3 | |
| 14.7 | | 13.8 | | 14.3 | | 12.4 | |

A total of 64 stomach samples were studied. 15,13,10,13 samples were analyzed from spring, summer, autumn, and winter, respectively.

Before the identification process, the wet weight of samples with stomach membrane was recorded by precision scales (Precisa XB 220A) with a scale sensitivity of 0.0001 gram. After that, membranes were carefully separated from the stomach contents (Figure 2.3). Stomach contents were washed by pouring water to retain microscopic organisms and put on blotter paper to avoid excessive water and weighed again. Next, the samples were examined under the light microscope (Olympus SZX12) with a 20x scale and identified. Finally, different contents were drawn with vacuum motors to remove their wetness, weighed separately and precision scales and relative diet compositions by weight were calculated for per identified stomach contents.

## 2.3 Ecological Modelling

### 2.3.1 Modelling Approach

Ecopath with Ecosim(EwE) version 6.6 (ecopath.org) was used to set up a food web model of the study area to investigate the trophic impact of *N. randalli*. Ecopath with Ecosim has three basic components: Ecopath, Ecosim and Ecospace. Ecopath uses linear equations to show trophic interactions among functional groups and provides mass balanced static information for a specific period (Christensen & Pauly, 1992). Ecosim is the time dynamic simulation for policy exploration by showing past and future impacts of environmental disturbances and fisheries in addition to examining the ecosystem, ecosystem’s resources and its interactions periodically (Walters et al., 1997). Finally, Ecospace is the spatial and temporal module for discovering the impact and placement of protected areas besides accounting dispersal effects and migration (Walters et al., 1999). The Ecopath part of the modelling suite was used. Ecopath is the mass-balanced static system and works with two master equations;

Consumption(Q)=Production(P)+Respiration(R)+Unassimilated food(E)

and

$$Pi - M2i - M0i - Ei - Yi - BAi \cong 0$$

where $Pi$ is the total production of functional group $i$, $M2i$ predation mortality, $M0i$ is the other mortality rate excluding catches or predation of $i$, $Ei$ is the net migration rate of $i$, $Yi$ is the totally fishery catch rate of $i$, $BAi$ is the biomass accumulation rate of $i$.

This equation can be expressed as;

$$B_i * \left(\frac{P}{B}\right)_i - \sum_{j=1}^{n} B_j * \left(\frac{Q}{B}\right)_j DC_{ji} - (1 - EE_i) * B_i * \left(\frac{P}{B}\right)_i - E_i - Y_i - BA_i = 0$$

where $B_i$ is the biomass of group i, $\left(\frac{P}{B}\right)_i$ is the production biomass ratio for i, $\left(\frac{Q}{B}\right)_j$ is the consumption biomass ratio of predator j, $DC_{ji}$ is the fraction of prey i in the average diet of predator j, $EE_i$ is the ecotrophic efficiency of i.

Ecopath requires three of the four parameters; biomass(B), production per unit of biomass (P/B), consumption per unit of biomass (Q/B), and ecotrophic efficiency (EE), specified, and the unknown parameter is estimated by Ecopath. Further, a relative diet composition matrix is required for Ecopath. Additionally, catch rates for fished groups can be provided.

### 2.3.2 Functional Groups

Functional groups/species included in the model were constituted depending on the direct or indirect interaction with *N. randalli,* the focal group in the model. The model included groups with direct interaction as preys or predators of *N. randalli*, with indirect interactions that are competitors to *N. randalli* by exploiting similar food resources. While functional groups of zooplankton, benthic invertebrates, polychaetes, benthic small crustaceans, shrimps, Sparidae, *Serranus* spp., ponyfishes and Clupeidae were involved as the prey, *Saurida undusquamis* were added as a predator and *P. erythrinus*, *P. acarne*, *M. barbatus* and *M. surmuletus* were included as competitors of *N. randalli*. Groups with no direct or indirect interactions with *N. randalli* but represented in the model were included as they were coupled to other groups included in the model as preys or first-order predators. Functional groups were formed based on their similarity in dietary requirements and having common predators. In total, thirteen functional groups and seven species were defined. Functional groups are shown in Table 2.2.

Table 2.2 List of functional groups in the model

| **Group name** | **Species** |
|---|---|
| Phytoplankton | - |
| Zooplankton | - |
| *Nemipterus randalli* | - |
| Benthic invertebrates | *Philine sp., Anseropoda placenta, Echinaster sepositus, Pennatula phosphorea, Pennatula rubra, Antedon, Coscinasterias tenuispina* |
| Polychaetes | |
| Small benthic crustaceans | *Pagurus prideaux, Dorippe lanata, Charybdis longicollis, Squilla mantis, Oratosquilla massavensis* |
| Shrimps | *Penaeus japonicus, Penaeus kerathurus, Parapeneus longirostris* |
| Octopuses and Cuttlefish | *Eledone moschata, Octopus vulgaris, Sepia officinalis, Illex coindetii, Loligo vulgaris, Sepia elegans, Sepia orbignyana, Sepietta oweniana* |
| *Pagellus erythrinus* | - |

Table 2.3 (continued)

| | |
|---|---|
| *Pagellus acarne* | - |
| *Mullus barbatus* | - |
| *Mullus surmuletus* | - |
| *Merluccius merluccius* | - |
| *Gobius spp.* | *Gobius buchichii, Gobius niger jozo, Vanderhorstia mertensi* |
| *Saurida undosquamis* | |
| Sparidae | *Boops boops, Dentex macrophthalmus, Diplodus annularis, Diplodus sargus, Diplodus vulgaris, Lithognathus mormyrus, Pagrus ehrenbergi,Pagrus pagrus, Sparus aurata, Spicara flexuosa, Spicara smaris* |
| Serranus spp. | *Serranus cabrilla, Serranus hepatus* |
| Ponyfishes | *Equulites elongatus, Leiognathus klunzingeri* |
| Clupeidae | *Dussumieria elopsoides, Sardina pilchardus, Sardinella aurita, Sardinella madarensis* |
| Detritus | - |

### 2.3.3 Biomass

Biomass of *Nemipterus randalli,* benthic invertebrates, small benthic crustaceans, shrimps, octopuses and cuttlefish, *Pagellus erythrinus, Pagellus acarne, Mullus surmuletus, Merluccius merluccius, Gobius spp., Saurida undosquamis,* Sparidae, *Serranus* spp., ponyfishes, clupeidae were calculated with swept area method by using data from the monthly trawl surveys in 2019. Phytoplankton's, zooplankton's and polychaetes' biomass were obtained from literature. Swept area (a) or "the effective of path swept" is estimated by;

$$a = D * hr * X$$

where D is the cover distance, hr is the length of the head-rope, and $X$ is the fraction of the head-rope length which is equal to the width of the path swept by the trawl.

$$\mathrm{D} = 60 * \sqrt{(Lat_1 - Lat_2)^2 + (Lon_1 - Lon_2)^2 * cos^2(0.5 * Lat_1 + Lat_2)})$$

where $Lat_1$ is starting latitude, $Lat_2$ is final latitude, $Lon_1$ starting longitude, $Lon_2$ final latitude.

Biomass of functional groups were calculated by the following the formula;

$$\frac{C_W}{a}$$

where $C_W$ is catch weight and a is the swept area. Then it was converted to tons/km$^2$ to use in the model.

### 2.3.4 Consumption/Biomass

Consumption/Biomass rates were calculated for functional group of fish species (Table 2.2) with the formula;

$$\log(\text{Consumption/Biomass}) =$$
$$7.9640.204*\log W_\infty 1.965*T+0.083*A+0.532*h+0.398*d$$

Pauly et al. (1998)

where $W_\infty$ is asymptotic weight (wet weight in g), A is the aspect ratio of the fish tail which gives an idea about level of activity of the fish. For example, higher aspect ratio means higher metabolic rates of food consumption of fish. h=1 when fish is herbivore and h=0 when fish is not herbivore, d=1 when fish is a detritivore and d=0 when fish is not detritivore. T is the mean habitat temperature calculated by 1000/Kelvin (Kelvin = °C + 273.15).

$$W_\infty = a * L_\infty^b$$

where $L_\infty$ is asymptotic length, a is the intercept and b is the exponent, indicating allometric or isometric growth.

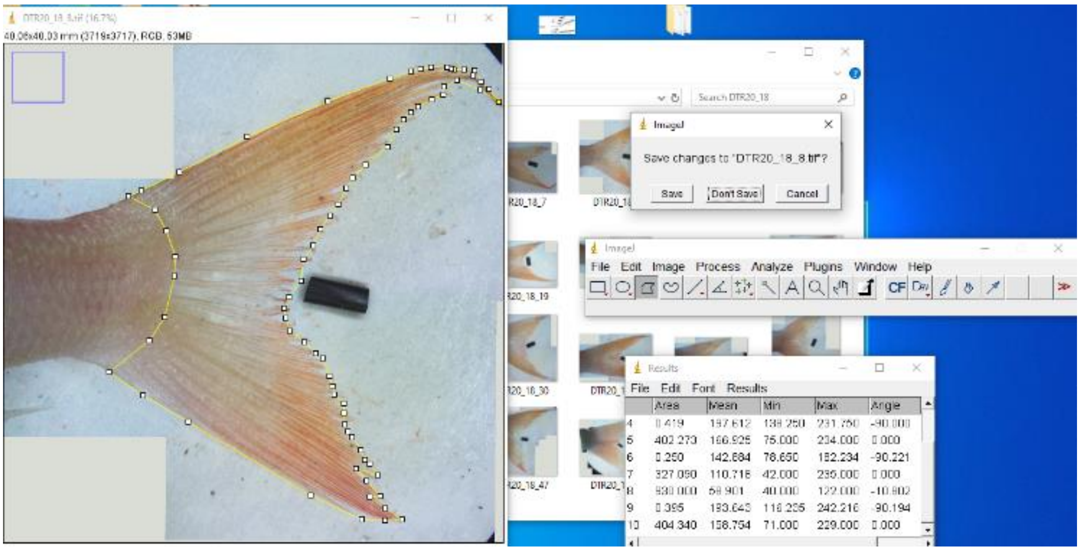
Aspect ratios for all the fish groups except *N. randalli* were obtained from the literature. The aspect ratio of *N. randalli* was calculated using sampled specimens using the formula;

$$A = \frac{h^2}{s}$$

where h is the height of the caudal fin and s is the surface area of the fin.

Fifty tail samples of *N. randalli* were selected from the last five trawling stations in order not to lose their tail structure by freezing them and to make appropriate measurements. Chosen samples represented lengths from 4cm to 21cm. They were photographed with a microscope camera (Olympus DP26). Then their height and surface area were measured with ImageJ (https://imagej.nih.gov/ij/) as shown in Figure 2.4. Their median value was used for the calculation of the aspect ratio. Also, length weight relationships were calculated from five stations that had samples from different lengths. $L_{max}$ (maximum length of fish) values were taken from the trawl survey results, and $L_\infty$ was calculated for five stations. Then Q/B values were calculated for these five stations respectively. The median Q/B value of five stations was used for *N. randalli* in the model. The asymptotic length was calculated with;

$$L_\infty \approx \frac{L_{max}}{0.95}$$



Save changes to 'DTR20_18_8.tif'?

```
     Area     Mean     Min      Max      Angle
4    0.419    197.612  138.250  231.750  -90.000
5    402.273  166.925  75.000   234.000  0.000
6    0.250    142.684  78.650   182.234  -90.221
7    327.090  110.718  42.000   235.000  0.000
8    930.000  58.901   40.000   122.000  -10.802
9    0.395    193.643  118.235  242.216  -90.194
10   404.340  158.754  71.000   229.000  0.000
```

Figure 2.3 Aspect ratio calculation by ImageJ

Other fish functional groups' asymptotic weights were obtained from studies, as shown in Table 2.3. Aspect ratio of fish species were taken from FishBase (Froese and Pauly, 2022) except for *Merluccius merluccius*, *Mullus barbatus* and *Mullus surmuletus*. Their aspect ratios were obtained from the studies by Soykan et al. (2015), Celik and Torcu (2000), and Kousteni et al. (2019), respectively. Temperature values for fish species were obtained from the bottom temperature of trawl stations.

Table 2.4. References of asymptotic weight and aspect ratio values

| **Species** | **Winf** | **References (Winf)** | **Aspect ratio** |
|---|---|---|---|
| **Clupeidae** | | | |
| *Dussumieria elopsoides* | 150 | Padilla (1991) | 2.33 |
| *Sardina pilchardus* | 27.95 | Akyol et al. (1996) | 2.13 |
| *Sardinella aurita* | 134.8 | Mater et al. (2003 | 1.59 |
| *Sardinella madarensis* | 133 | FAO (1982) | 3 |

Table 2.5 (continued)

| | | | |
|---|---|---|---|
| ***Mullus barbatus*** | 274.28 | Celik and Torcu (2000) | 1.97 |
| ***Mullus surmuletus*** | 475.45 | Kousteni et al. (2019) | 1.38 |
| **Sparidae** | | | |
| *Boops boops* | 303 | Soykan et al. (2015b) | 0.97 |
| *Dentex macrophthalmus* | 231 | Soykan et al. (2015b) | 0.96 |
| *Diplodus annularis* | 105 | Koc et al. (2002) | 1.58 |
| *Diplodus sargus* | 679.39 | Benchalel and Kara (2013) | 3.24 |
| *Diplodus vulgaris* | 425 | Soykan et al. (2015b) | 4.72 |
| *Lithognathus mormyrus* | 660.9 | Türkmen and Akyurt (2003) | 2.87 |
| *Pagrus ehrenbergi* | 556.72 | Elawad et al. (2017) | 2.02 |
| *Pagrus pagrus* | 556.72 | Elawad et al. (2017) | 2.02 |
| *Sparus aurata* | 393.93 | Apostolidis and Stergiou (2014) | 1.39 |
| *Spicara flexuosa* | 37.4 | Yeldan et al. (2003) | 2.86 |
| *Spicara smaris* | 37.4 | Yeldan et al. (2003) | 2.86 |
| ***Merluccius merluccius*** | 1455.77 | Soykan et al. (2015a) | 1.32 |
| **Gobius spp.** | | | |
| *Gobius buchichii* | 33.32 | Filiz and Togulga (2009) | 0.65 |
| *Gobius niger jozo* | 33.32 | Filiz and Togulga (2009) | 0.99 |
| *Vanderhorstia mertensi* | 33.32 | Filiz and Togulga(2009) | 0.61 |
| **Serranus spp.** | | | |
| *Serranus cabrilla* | 119.27 | İlhan et al. (2010) | 1.18 |
| *Serranus hepatus* | 39.38 | Soykan et al. (2013) | 1.38 |
| ***Saurida undusquamis*** | 972.37 | Mehanna et al. (2014) | 1.93 |
| ***Pagellus erythrinus*** | 345.41 | Metin (2011) | 1.9 |
| ***Pagellus acarne*** | 152.97 | Soykan et al. (2015b) | 2.6 |

Other functional groups' (zooplankton, benthic invertebrates, polychaetes, small benthic crustaceans and shrimps) consumption/ biomass rates were taken from previous modelling studies in the Mediterranean Sea (Saygu,2020; Tsagarakis et al.,2010; Corrales et al., 2017; Cammen,1980).

### 2.3.5 Production/Biomass

P/B ratio for teleost fishes were calculated with;

$$\ln Z = 1.46-1.01*\ln(A_{max}) \text{ Hoenig (1983)}$$

where Z signifies total mortality (P/B ratio) and $A_{max}$ signifies maximum age of species.

P/B values of Sparidae, Clupeidae, *Gobius* spp., *Serranus* spp. were calculated using the weighted averages of the P/B values of each species in the respective functional groups. Mortalities of other fish functional groups were obtained from literature or estimated from the formula by using the references in Table 2.4. Mortality ratios of benthic invertebrates, polychaetes, benthic small crustaceans, shrimps, and octopuses and cuttlefish functional groups were obtained from previous studies (Saygu, 2018; Brey, 2012). The maximum age of *N. randalli* was taken as three according to studies by Erguden et al. (2010).

Table 2.6 Fish functional groups' age and mortality references

| **Species** | **References of Studies for age and mortality** |
|---|---|
| *Nemipterus randalli* | Erguden et al. (2010) |
| *Pagellus erythrinus* | Çiçek et al. (2012) |
| *Pagellus acarne* | Soykan et al. (2015b) |
| *Mullus barbatus* | Cicek (2015) |
| *Mullus surmuletus* | Mehanna (2009) |

Table 2.4 (continued)

| | |
|---|---|
| *Merluccius merluccius* | Soykan et al (2015) |
| *Gobius* spp. | Kırdar, F., and İşmen, A., (2018) |
| *Saurida undosquamis* | Gökçe et al. (2007) |
| Sparidae | Skoko et al. (2007),<br>Dulcic et al. (2011),<br>Soykan et al. (2015b)<br>Manaşırlı et al. (2006)<br>Vassilopoulou and Papaconstantinou, (1992)<br>Vidalis and Tsimenidis (1996),<br>(Mehanna, 2007),<br>Emre et al. (2010) |
| *Serranus* spp. | Dulcˇic´ et al (2007), (Rachedi M, Dahel A.T., 2019) |
| *Equulites elongatus* | Ozutok and Avsar(2004) |
| Clupeidae | (Salem, M., El_Aiatt, A.A. Ameran, M, 2010),(Wassef, E., Ezzat, A., Hashem, T., Faltas S., 1985),(Erdoğan, Z., Torcu Koç, H., Gicili, S., Ulunehir, G., 2010) |

### 2.3.6 Diet

In this study, *N. randalli's* stomach content was analyzed in the laboratory. The relative diet composition of *N. randalli* was calculated as percent wet weight. Diets of other functional groups were taken from local studies, other Mediterranean models and literature (Appendix A). The diet data of functional groups were modified to provide balance in the model (Table 3.4).

### 2.3.7 Catches

Catch data were taken from the official landing statistics (TUİK,2020). This statistical data covered all Mediterranean coasts of Turkey, and there was no information about the geographical locations. The data were divided into the total area of Turkey's Exclusive Economic Zone (EEZ) to obtain annual catch rates in tons per square kilometer. However, EEZ total areas were conflicted because of political issues. One of the approaches suggests total areas of EEZ in the Basin is 145.000 $km^2$ whereas the other suggests 41.000 $km^2$ (Çubukçuoğlu,2014; Yaycı,2013).

A total area of 72,195 $km^2$ was used to avoid conflict between studies(seaaroundus.org). Since Turkey does not have any statistical data for *N. randalli,* its catch data were taken as nil for the original model.

Table 2.7 Catch data and references for functional groups

| **Species** | **Catch (tons km$^{-2}$ year$^{-1}$)** |
|---|---|
| Benthic small crustacae | 6.51015E-05 |
| Shrimps | 0.016039892 |
| Octopuses and Cuttlefishes | 0.00801025 |
| *Pagellus erythinus* | 0.008792853 |
| *Mullus barbatus* | 0.012121338 |
| *Mullus surmuletus* | 0.000464021 |
| *Merluccius merluccius* | 0.000522197 |
| *Gobius* spp. | 0.0008574 |
| *Saurida undosquamis* | 0.000824157 |
| Sparidae | 0.018094051 |
| Clupeidae | 0.050732045 |

### 2.3.8 Mixed Trophic Impact and Keystoneness Index

Mixed trophic impact analysis was used to understand *N. randalli's* negative or positive impacts on other functional groups. It also helped to show how groups were affected by each other in the food web. Mixed Trophic Impact (MTI) analysis indicates the direct and indirect trophic interactions between functional groups (Ulanowicz & Puccia, 1990). The direct impact of one group on another is related to predation or fishery, although indirect impacts might be caused by competition for prey or trophic cascades exerted by other groups in the food web. Functional groups have a generally negative impact on themselves while they compete for the same resources. In the model, trawlers were treated as a functional group in the analysis. Mixed trophic impact values scale from +1(positive effect) to -1(negative effect). Mixed Trophic Impact (MTI) is calculated with;

$$m_{ij} = \prod_{i=1}^{n}(d_{ji} - f_{ij})$$

where $d_{ji}$ signifies positive effects that prey i has on predator j, which is calculated by means of the fraction of prey in the predator's diet and $f_{ij}$ indicates negative effects that predator j has on prey i, which is calculated by the fraction of total consumption of prey by the predator (Libralato et al., 2006).

The keystoneness index (KS) was used to predict keystone groups, which have relatively low biomass values but structuring roles in the food web. Keystone groups are described as important groups to influence the ecosystem dynamics despite having low biomass (Power et al., 1996), Keystone value of each group was calculated by;

$$\varepsilon_i = \sqrt{\sum_{j \neq i}^{n} m_{ij}^2}$$

$$KS_i = \log[\varepsilon_i(1 - \mathrm{p}_i)]$$

where $\varepsilon_i$ is the overall impact on group $j$, $m_{ij}$ is the net MTI excluding group impact itself, $KS_i$ is the keystoneness of the group i, $\mathrm{p}_i$ is the ratio of the biomass of group i to the sum of the biomass of all groups except detritus (Libralato et al. ,2006).

### 2.3.9 Summary Statistics, Network Analysis and Ecological Indicators

Odum (1969) suggested a concept of ecosystem maturity, meaning ecosystems evolve in succession toward maturity. Developing systems compared to the mature ones have lesser capacity to entrap and hold nutrients for cycling in the system. He described 24 attributes to characterize ecosystem development. EwE was used to calculate some of these synthetic ecological indicators, flows between trophic levels and to carry out network analysis to understand the structure and functioning of the food web. (Odum;1969; Finn,1976; Ulanowicz,1986; Christensen,1995; Heymans et al., 2014).

#### 2.3.9.1 Ecosystem Theory Indices

Based on diet composition, Ecopath calculated trophic level of each functional group by the following equation;

$$\mathrm{T}L_j = 1 + \sum_{j=1}^{n} DC_{ji} * TL_i$$ (Christensen et al.,2008)

where $DC_{ij}$ is the proportion of prey i in the diet of predator j, $TL_i$ is the trophic level of the prey i.

Total system throughput is another indicator for the determination of the size of the entire system. It is the sum of total consumption, total export, total respiration and total flows into detritus and calculated with formula;

$$\text{TST}=\sum_{i=1,j=1}^{n} T_{ij} \quad \text{(Finn,1976)}$$

where i is the prey and j is the predator.

Total net primary production/ total respiration (TPp/TR) gives an idea about maturity of the ecosystem. A ratio of TPp/TR close to 1 indicates a mature ecosystem; a ratio less than 1 indicates an ecosystem with organic pollution; finally, a ratio higher than 1 indicates a developing ecosystem. Net system production is defined as the difference between total net primary production and total respiration and is expected to be close to nil in mature ecosystems. Furthermore, immature systems tend to have a high total primary production/total biomass (TPp/TB) ratio. Another indicator for ecosystem maturity and showing development status is respiration to biomass(R/B) ratio which is also known as the Schrodinger ratio (Odum and Barrett,1971). The ratio R/B tends to be lower for mature ecosystems than for developing ecosystems.

Transfer efficiency shows the efficiency of energy transfers between trophic levels. Producers and detritus groups contributed to the first TL. Then, herbivorous fraction of flows and biomass were added to TL II and first order carnivorous flows to TL III. Finally, second order carnivorous flows and biomass were contributed to TL IV. Mean transfer efficiency was also calculated as a geometric mean from TL II to TL IV (Christensen et al.,2005). Flows between trophic levels are shown with the Lindeman spine (Lindeman,1942; Ulanowicz,1986).

System omnivory index (SOI) is developed for showing complexity and connectivity of the food web which allows comparison of ecosystems by assessing their development stage and maturity**.** Developed and mature ecosystems show higher values of SOI(Libralato,2013). A low omnivory index indicates that general consumers feed on a single trophic level, such as linear networks (Torres et al., 2013). It is calculated based on the omnivory index and is defined for each functional group by the formula of;

$$OI_i = \sum_{j=1}^{n} (TL_j - (TL_i - 1)^2 * \left(DC_{ij}\right)$$

(Christensen et al.,2005)

$$SOI = \frac{\sum_{i=1}^{n} [OI_i * \log(Q_i)]}{\sum_{i=1}^{n} \log(Q_i)}$$

(Christensen and Walters,2004)

where $Q_i$ is consumption of each predator separately. High OI infers that the diet preferences of predator is more complex(generalist).

Mean trophic level of the community was calculated excluding groups with trophic levels=1 (phytoplankton and detritus). It gives information on which trophic levels are predominant. Rise of the mean trophic level of community implies the increasing significance of fishing impact (Libralato et al., 2005).

$$mTL_{CO} = \frac{\sum_i TL_i * B_i}{\sum_i B_i}$$

(Christensen et al,2005)

where $B_i$ is the biomass of functional group i.

#### 2.3.9.2 Cycle and Pathway Indices

The Finn Cycling Index (FCI) evaluates the quantitative importance of cycles in the given ecosystems. It is calculated as;

$$FCI = \frac{TST_c}{TST}$$

(Finn,1976)

where TST is the total system throughput and $TST_c$ is total flow which is recycled. Finn Cycling Index is related to ecosystem maturity, meaning that a higher value indicates a more mature ecosystem. In addition to FCI, throughput cycled excluding detritus, predatory cycling index, throughput cycled including detritus and Finn's mean path length were calculated to assess material and energy cycling in the ecosystem.

#### 2.3.9.3 Information Indices

Ascendency evaluates the level of system activity and the degree of its organization (Ulanowicz,1986). Higher ascendency is associated with healthier ecosystems (Costanza and Mageau,1992). Ascendency is related with average mutual information (AMI) and calculated as;

$$A = \sum_{ij} (T_{ij}) * log \frac{T_{ij} * TST}{T_i * T_j}$$

(Ulanowicz,1986)

where TST is total system throughput and $T_{ij}$ is the flow from compartment i to compartment j.

### 2.3.10 Balancing Model

Model is considered balanced when ecotrophic efficiencies are smaller than unity. In addition, ecologically and thermodynamically Production/Consumption (P/Q) values should scale between 0.1 and 0.3 (consumption of most groups is about 3-10 times higher than their production), Production/Respiration (P/R) and Respiration/Assimilation(R/A) should be smaller than unity to provide static mass-balanced assumption of ecosystem resources and their interactions.

Before the model was balanced, pre-balance (PREBAL) diagnostics was applied to check the slopes of Biomass, Production/ Biomass, Consumption/Biomass and

Production/Consumption. Thus, functional groups were expected to conform to the slope lines. The pedigree index was used to show the uncertainty in the input data (Christensen et al.,2008) and ranges between 0 (high uncertainty) and 1(low uncertainty).

### 2.3.11 Scenarios

Two scenarios were created to test how *N. randalli*'s impact changes native species and fishery under its decreasing population by landing for first scenario and predation or higher mortality rates. These scenarios are: i) *N. randalli* is commercially fished; ii) *N. randalli*'s population declined . In the first scenario (commercial fishery), a hypothetical catch for *N. randalli* was introduced to the model(catch/biomass=0.43) without disturbing the balance in the model (EE < 1). In the second scenario (population decrease), *N. randalli*'s biomass was decreased by a factor of 0.3 while not disturbing the balance in the model. In both scenarios, mixed trophic impact, keystoneness index, and the Lindeman spine graphs were calculated and compared with each other.

# CHAPTER 3

# RESULTS

## 3.1 Laboratory Studies

The diet composition of *N. randalli* was calculated in percentage composition by weight (%w) by dividing each identified contents' weights separately by the total stomach content weight (45.2771 g). Thirteen stomachs were empty in total. There were 7,3,1, and 2 empty stomachs collected from the winter, spring, summer, and autumn seasons, respectively. The shortest fish with an empty stomach was 11cm, and the longest was 21cm. Contents such as endoparasite, unidentified digested organic material, and lophotrochozoan were grouped under the detritus group. The weights of unidentified fish groups in the stomachs were proportionally added to the fractions of other fish groups in the diet based on their average weights. Results were categorized under related functional groups, shown in Table 3.1.

Table 3.1 Diet composition of *Nemipterus randalli* according to functional groups in the model

| Species | %W |
|---|---|
| **Benthic small crustacean** | 55.76 |
| *Macrura reptantia* | 0.09 |
| Stomatopoda | 6.10 |
| *Squilla sp.* | 26.99 |
| *Charybdis longicollis* | 10.95 |
| Crab | 9.49 |
| *Macrophthalmus* sp. | 0.94 |
| Unidentified Crustacea | 1.20 |
| **Shrimp** | 9.13 |
| Alphediae | 0.12 |

Table 3.1 (continued)

| | |
|---|---|
| *Melicertus kerathurus* | **2.94** |
| *Penaeus japonicus* | 4.26 |
| *Penaeus* sp. | 0.53 |
| **Benthic Invertebrate** | 0.88 |
| *Anseropoda placenta* | 0.11 |
| Echinodermata | 0.02 |
| *Ophiaderma longicauda* | 0.75 |
| ***Saurida undusquamis*** | 1.98 |
| **Sparidae** | 1.55 |
| **Clupeidae** | 16.96 |
| ***Serranus* spp.** | 6.19 |
| *Serranus hepatus* | 4.49 |
| ***Gobius* spp**. | 2.45 |
| Vanderhorstia mertensi | 1.78 |
| **Ponyfishes** | |
| Equulites elongatus | 3.48 |
| **Detritus** | 2.56 |
| Endoparasite | 0.29 |
| Digested organic material | 0.39 |
| Lophotrochozoa | 1.88 |

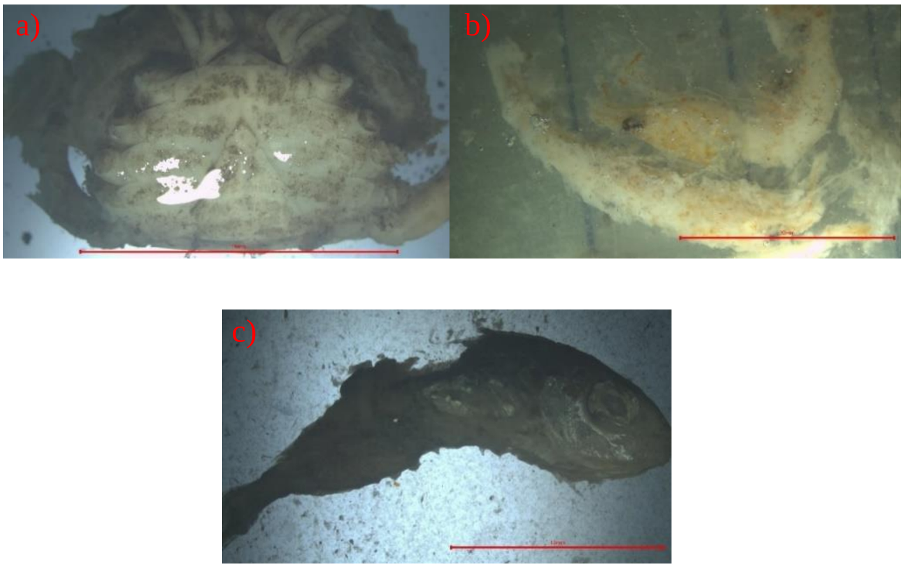


Figure 3.1 *Charybdis longicollis*(a), shrimps(b), unidentified fish(c) in the stomachs of *N. randalli* individuals.

## 3.2 Balanced Model Outputs

PREBAL results showed that the biomasses of zooplankton, polychaetes, and phytoplankton were above the slope line. It indicates that they might be underestimated, while benthic invertebrates, benthic small crustacea, and shrimps may be overestimated because they were below the slope line. The production biomass ratio of phytoplankton and zooplankton may be underestimated due to their higher value than expected model balanced line. The consumption biomass rate of zooplankton may also be underestimated because of its higher rate than expected PREBAL line. Unmatching estimation of the PREBAL graphs may result from the input data of these functional groups (phytoplankton, zooplankton, polychaetes) obtained from other models. Overall, functional groups showed linear positive trend through prebalancing graphs. Furthermore, Respiration/Biomass was between 1–10 years for fish functional groups and within the expected limits. Results showed that the P/Q ratio of *N. randalli* was 0.092, Spharidae was 0.090, and Clupeidae was 0.098. They were lower than expected theoretical values (0.1-0.30). Choosing or calculating P/B values for individuals in Spharidae and Clupeidae functional groups may be the reason for this result by including more than one fish species. Likewise, choosing the stations' median value of Q/B of *N. randalli* may be the reason for this result. This problem may be fixed by calculating more samples of *N. randalli* from different stations. However, these results were still valid for balancing the model.

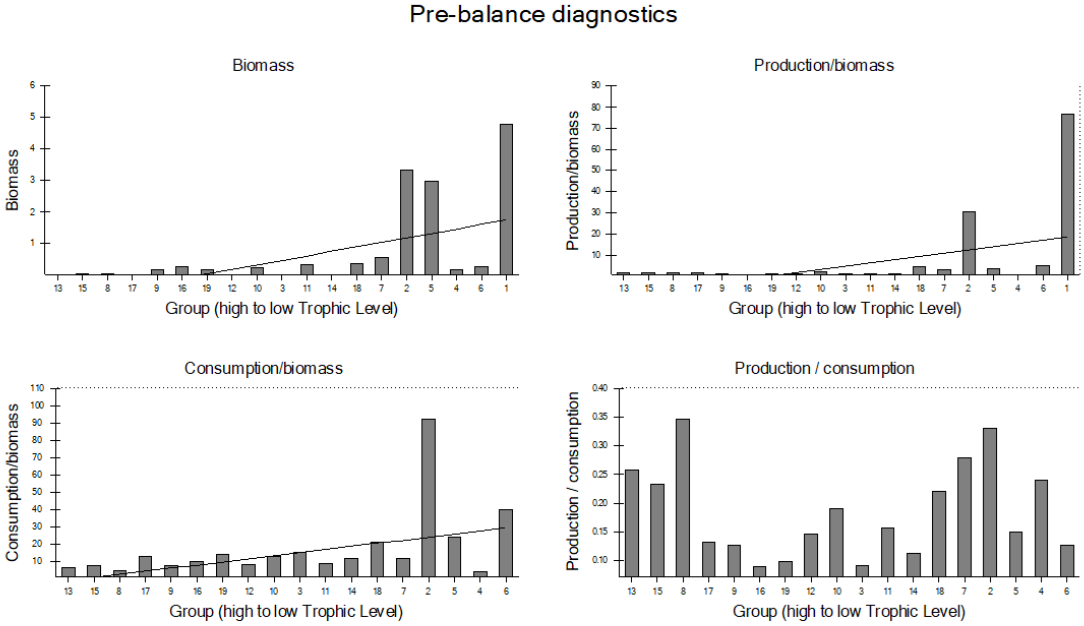


Figure 3.2 PREBAL of the model (1) Biomass estimates (t. km$^{-2}$), (2) Production/Biomass ratio (y$^{-1}$), (3)Consumption/Biomass (y$^{-1}$), (4) Production/Consumption on a logarithmic scale and functional groups ranked from the lowest to the highest trophic level.

### 3.2.1 Model Parameters

According to trawl survey results, the highest biomass of *N. randalli* was observed in around 60m depth at the beginning of spring and later in summer. Biomass of all functional groups except phytoplankton, zooplankton, and polychaetes were calculated using 2019 trawl survey results. Results are shown in Table 3.3.

Consumption/ Biomass ratio of *N. randalli* was calculated by using the log weight and log length graph (Figure 3.3). The Intercept of the regression curve (a in the asymptotic weight formula) was calculated from the curve by 0.016. The slope (b in the asymptotic weight formula) was 3.026 (Figure 3.3). $L_{max}$, $L_{inf}$, $\log W_{inf}$, mean aspect ratio and temperature values for five stations are shown in Table 3.2.

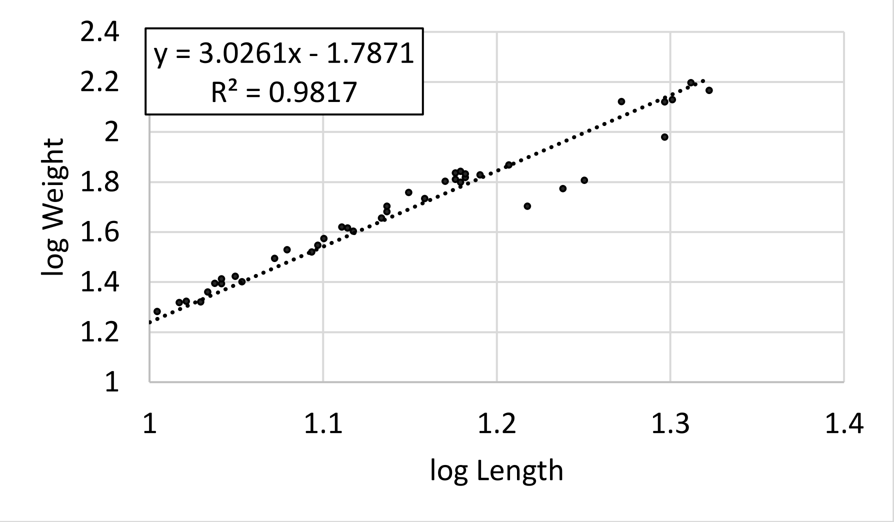


Figure 3.3 Intercept of the regression curve(a) and regression coefficient (b) calculation graph from five station.

Table 3.2 Consumption/Biomass calculation from five stations

| | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| **Lmax** | 18.7 | 17.5 | 16.1 | 14.4 | 21 |
| **Linf** | 19.68421 | 18.42105 | 16.94737 | 15.15789 | 22.10526 |
| **logWinf** | 2.12903 | 2.041868 | 1.932286 | 1.785631 | 2.281478 |
| **Mean aspect ratio** | 2.601178 | 3.529252 | 3.741785 | 2.096499 | 3.521275 |
| **Temperature (Kelvin)** | 299.6207 | 293.0346 | 302.3664 | 302.4164 | 294.3076 |
| Q/B | **15.3916** | **13.63622** | **24.07929** | **18.88327** | **13.00638** |

Table 3.3 Models Outputs

| | **Group name** | **Trophic level** | **Biomass in habitat area (t/km²)** | **Production / biomass (/year)** | **Consumption / biomass (/year)** | **Ecotrophic Efficiency** | **Production / consumption (/year)** | **Omnivory index** |
|---|---|---|---|---|---|---|---|---|
| **1** | Phytoplankton | 1.000 | 4.797 | 4.797 | 76.853 | | 0.585 | |
| **2** | Zooplankton | 2.053 | 3.338 | 3.338 | 30.418 | 92.180 | 0.262 | 0.330 |
| **3** | *N. randalli* | 2.990 | 0.020 | 0.020 | 1.420 | 15.390 | 0.696 | 0.092 |
| **4** | Benthic invertebrates | 2.033 | 0.179 | 0.179 | 0.942 | 3.927 | 0.984 | 0.240 |
| **5** | Polychaetes | 2.035 | 3.010 | 3.010 | 3.609 | 24.060 | 0.999 | 0.150 |
| **6** | Benthic small crustaceans | 2.030 | 0.269 | 0.269 | 5.000 | 39.590 | 0.862 | 0.126 |
| **7** | Shrimps | 2.330 | 0.550 | 0.550 | 3.180 | 11.430 | 0.882 | 0.278 |
| **8** | Octopuses and cuttlefish | 3.633 | 0.046 | 0.046 | 1.610 | 4.644 | 0.864 | 0.347 |
| **9** | *P. erythrinus* | 3.175 | 0.156 | 0.156 | 0.970 | 7.629 | 0.213 | 0.127 |
| **10** | *P. acarne* | 3.043 | 0.230 | 0.230 | 2.395 | 12.550 | 0.036 | 0.191 |
| **11** | *M. barbatus* | 3.035 | 0.328 | 0.328 | 1.390 | 8.887 | 0.084 | 0.156 |
| **12** | *M. surmuletus* | 3.050 | 0.013 | 0.013 | 1.160 | 7.884 | 0.972 | 0.147 |
| **13** | *M. merluccius* | 4.330 | 0.019 | 0.019 | 1.692 | 6.561 | 0.951 | 0.258 |
| **14** | *Gobius* spp. | 3.034 | 0.008 | 0.008 | 1.330 | 11.830 | 0.822 | 0.112 |
| **15** | *Saurida undosquamis* | 4.077 | 0.049 | 0.049 | 1.760 | 7.569 | 0.190 | 0.233 |
| **16** | Sparidae | 3.136 | 0.263 | 0.263 | 0.888 | 9.900 | 0.635 | 0.090 |
| **17** | *Serranus* spp. | 3.229 | 0.014 | 0.014 | 1.704 | 12.850 | 0.961 | 0.133 |
| **18** | Ponyfishes | 3.005 | 0.374 | 0.374 | 4.600 | 20.840 | 0.044 | 0.221 |
| **19** | Clupeidae | 3.052 | 0.171 | 0.171 | 1.357 | 13.780 | 0.999 | 0.098 |
| **20** | Detritus | 1.000 | 67.480 | 67.480 | | | 0.515 | |

Table 3.4 Diet matrix of the balanced model. The first row shows predators and the first column shows preys. Values are rounded to three decimals

| **Prey \ predator** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1-Phytoplankton** | 0.700 | | | | | | | | | | | | | | | | 0.045 | |
| **2-Zooplankton** | 0.050 | 0.005 | | | | 0.042 | | | 0.454 | | | | | | 0.049 | 0.050 | 0.928 | 0.954 |
| **3-*N. randalli*** | | | | | | | | | | | | | | 0.053 | | | | |
| **4-Benthic invertebrates** | | 0.001 | 0.005 | | 0.002 | 0.003 | 0.008 | 0.007 | 0.015 | 0.013 | 0.093 | | | 0.001 | 0.007 | | | 0.002 |
| **5-Polychaetes** | | 0.065 | 0.027 | 0.034 | 0.019 | 0.271 | | 0.388 | 0.488 | 0.891 | 0.279 | | 0.863 | | 0.608 | | 0.023 | 0.044 |
| **6-Benthic small crustaceans** | | 0.601 | | | 0.005 | 0.003 | 0.166 | 0.207 | 0.044 | 0.096 | 0.610 | 0.001 | 0.137 | | 0.022 | 0.308 | 0.004 | |
| **7-Shrimps** | | 0.082 | | | 0.002 | | 0.520 | 0.370 | | | | 0.096 | | 0.030 | 0.305 | 0.634 | | |
| **8-Octopuses and cuttlefish** | | | | | | | 0.211 | 0.005 | | | | | | | 0.002 | | | |
| **9-*P. erythrinus*** | | | | | | | 0.095 | | | | | | | 0.008 | | | | |
| **10-*P. acarne*** | | | | | | | | | | | | | | 0.053 | | | | |
| **11-*M. barbatus*** | | | | | | | | | | | | 0.012 | | 0.018 | 0.007 | | | |
| **12-*M. surmuletus*** | | | | | | | | | | | | | | 0.037 | | | | |
| **13-*M. merluccius*** | | | | | | | | | | | | 0.241 | | | | | | |
| **14-*Gobius spp.*** | | | | | | | | 0.004 | | | 0.018 | | | | | 0.008 | | |
| **15-*Saurida undosquamis*** | | | | | | | | | | | | | | 0.042 | | | | |
| **16-Sparidae** | | 0.007 | | | | | | 0.018 | | | | 0.485 | | 0.126 | | | | |
| **17-*Serranus spp.*** | | 0.033 | | | | | | | | | | | | 0.033 | | | | |
| **18-Ponyfishes** | | 0.040 | | | | | | | | | | | | 0.173 | | | | |
| **19-Clupeidae** | | 0.010 | | | | | | | | | | 0.165 | | 0.425 | | | | |
| **20-Detritus** | 0.250 | 0.157 | 0.968 | 0.966 | 0.972 | 0.682 | | | | | | | | | | | | |

### 3.2.2 Mixed Trophic Impact and Keystoneness Index

The MTI analysis was performed to show *N. randalli's* impact on the food web. According to the MTI (Fig.3.) results, *N. randalli* had a negative impact on all functional groups except zooplankton, benthic invertebrates, polychaetes, shrimps, *Gobius* spp. and *Saurida undusquamis*. *N. randalli* revealed negative impacts mostly on native species *Serranus* spp. (-0.430),ponyfishes(-0.135) benthic small crustaceans (-0.119), *M. surmuletus* (-0.0687), *P. erythrinus* (-0.0120), *M. barbatus* (-0.00789), Octopuses and cuttlefish (-0.00352).Its negative impacts on benthic small crustaceans and *Serranus spp.* were related to predation. However, its negative impacts on other native species were indirect and related to competition since their diets are similar to *N. randalli's*. On the other hand, *N. randalli* showed a low positive impact on zooplankton, benthic invertebrates, polychaetes, shrimps, and *Gobius* spp. because they were in *N. randalli*'s diet and *N. randalli* was in competition with their predators. The positive impact of *N. randalli* on *Saurida undusquamis* can be explained by their prey-predator relations.

MTI analysis also showed that *Saurida undusquamis* negatively impacted *P. acarne* and *M. surmuletus* besides *N. randalli* due to being their predator. *P. erythinus* negatively impacted *Gobius* spp. because of being their predator. Polychaetes had a negative effect on benthic invertebrate, benthic small crustacean and shrimp due to the competition with them. Furthermore, MTI analysis showed that trawling affected *P. erythinus* and *M. barbatus* negatively. Since they have a similar diet with *N. randalli* , the negative impact of trawling on these species may create an advantage for *N. randalli.* The overall MTI results demonstrated that all functional groups affected their own groups negatively as a result of their competition for the resources.

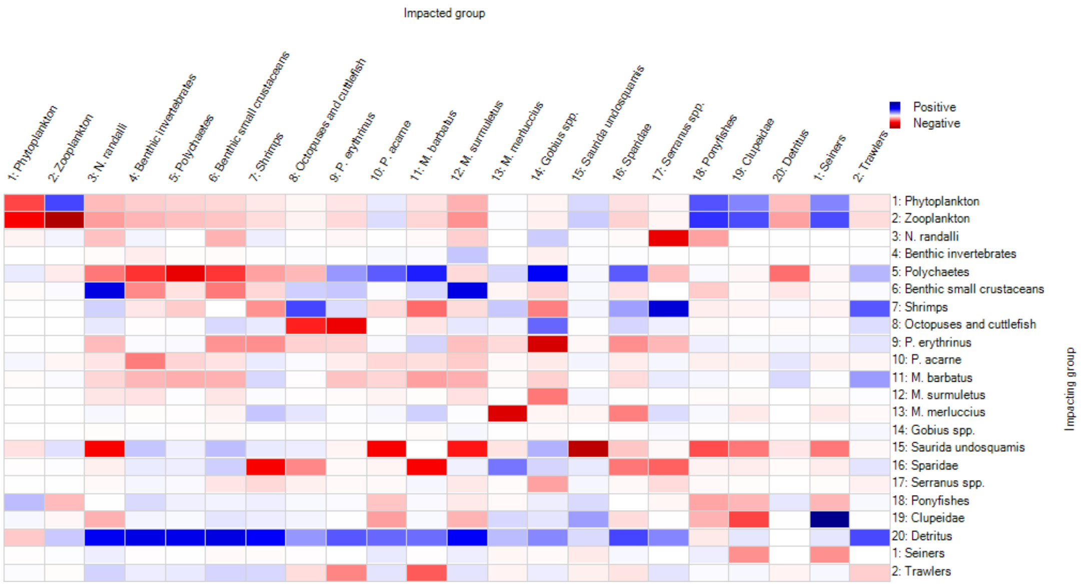


Figure 3.4 Mixed trophic impact (MTI) analysis. MTI values range between -1(red) and +1 (blue) ( -1 shows a strong negative impact while +1 shows a strong positive effect of the x-axis group on the y-axis group)

The keystoneness index (KS) was used to identify functional groups having a structuring role on the food web dynamics. Keystone species have lower biomasses but structuring roles in the ecosystem. In this model, keystoneness index (KS) of the functional groups revealed that *Saurida undusquamis* was the keystone group due to being predator of majority of functional groups in the food web with relatively low biomass and high overall impact. Also, polychaetes, benthic small crustacea and shrimps had high keystone index values. Moreover, *N. randalli* had a high keystone index value compared to other native species. It shows its importance in the structuring role in the ecosystem.

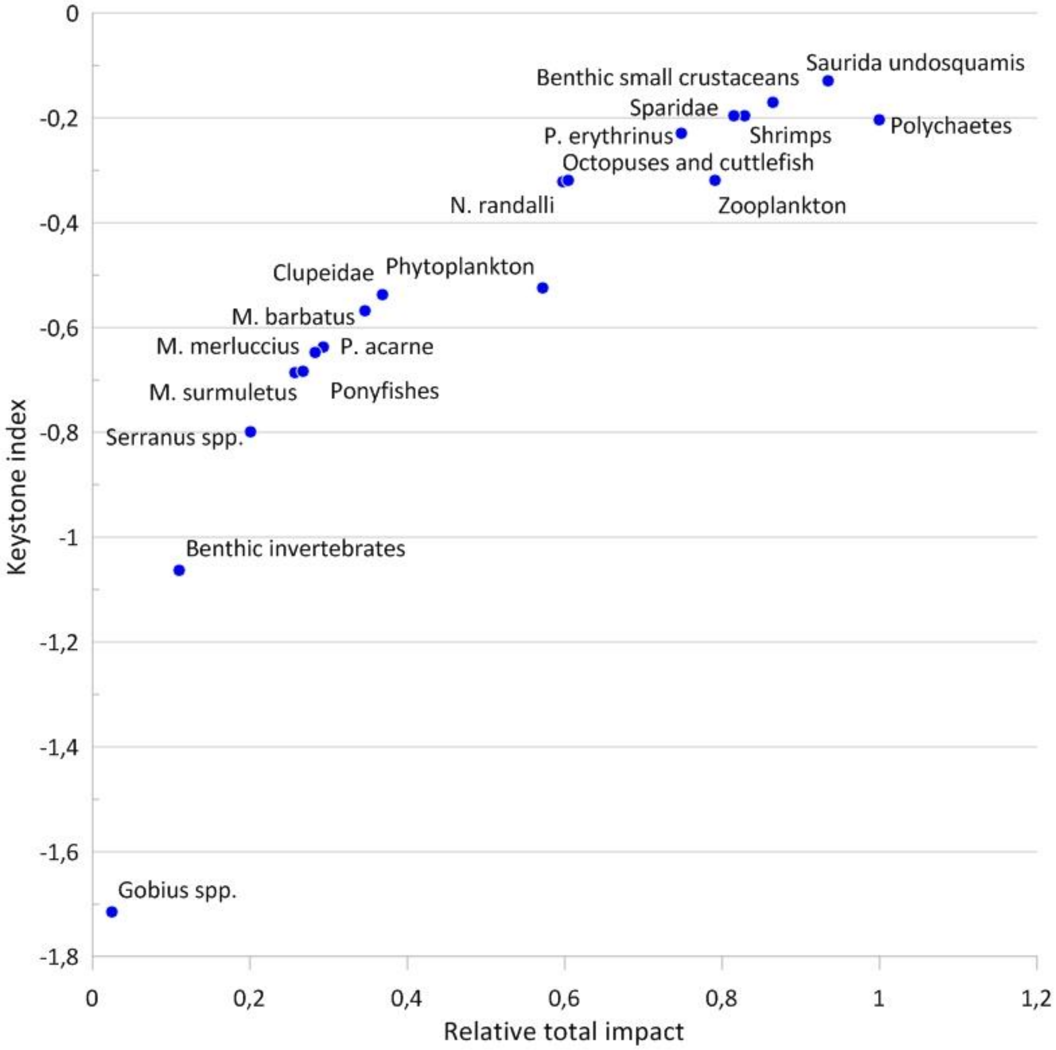


Figure 3.5 Keystoneness Index of Functional Groups

### 3.2.3 Summary Statistics, Ecological Indicators and Network Analysis

The model covered trophic levels 1 (phytoplankton and detritus) to 4.33 (*M.merluccius*) for thirteen functional groups. The trophic interactions between species are shown in Figure 3.6. *N. randalli* takes part in the middle of the flow diagram with trophic level 2.990.

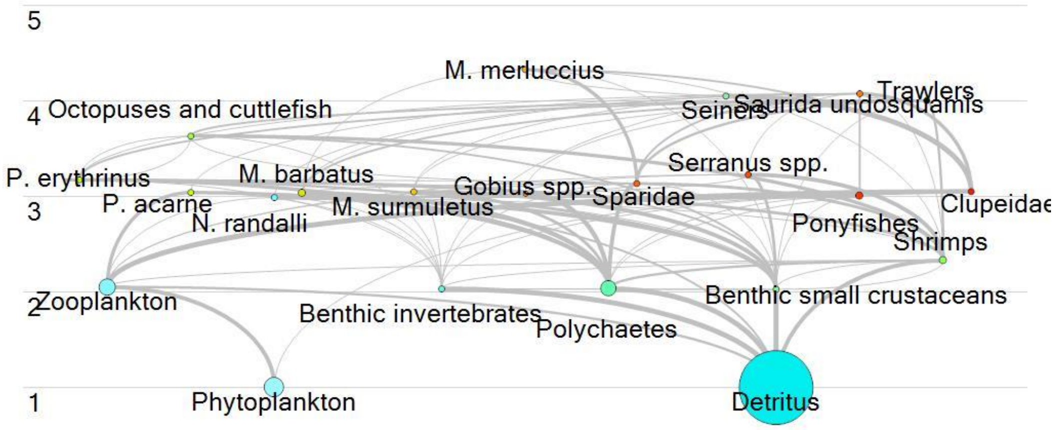


Figure 3.6 Flow diagram of the functional groups organized by their trophic levels. The size of circles indicates biomasses of functional groups

Summary statistics of the model are shown in Table 3.5. Cycling index and information indices results were used to compare the ecosystem maturity of the area with other models. The total system throughput (TST) and total biomass (excluding detritus) were calculated as 1100.378 t $km^{-2}$ $y^{-1}$ and 13.8014 t $km^{-2}$, respectively (Table 3.5).

Table 3.5 Summary statistics of model

| **Parameter** | **Value** | **Units** |
|---|---|---|
| Sum of all consumption | 418.8879 | t $km^{-2}$ $y^{-1}$ |
| Sum of all exports | 152.8281 | t $km^{-2}$ $y^{-1}$ |
| Sum of all respiratory flows | 215.8358 | t $km^{-2}$ $y^{-1}$ |
| Sum of all flows into detritus | 314.9589 | t $km^{-2}$ $y^{-1}$ |
| Total system throughput | 1102.511 | t $km^{-2}$ $y^{-1}$ |

Table 3.5 (continued)

| | | |
|---|---|---|
| Sum of all production | 487.9383 | t km$^{-2}$ y$^{-1}$ |
| Mean trophic level of the catch | 3.025302 | |
| Gross efficiency (catch/net p.p.) | 0.000316 | |
| Calculated total net primary Production (TPp) | 368.6638 | t km$^{-2}$ y$^{-1}$ |
| Total primary production/total respiration | 1.708076 | |
| Net system production | 152.828 | t km$^{-2}$ y$^{-1}$ |
| Total primary production/total biomass | 26.65034 | |
| Total biomass/total throughput | 0.01254714 | t km$^{-2}$ y$^{-1}$ |
| Total biomass (excluding detritus) | 13.83336 | t km$^{-2}$ |
| Mean transfer efficiency | 4.56 | % |
| Total catch | 0.1164263 | |
| Connectance Index | 0.2465374 | |
| System Omnivory Index | 0.06154883 | |
| Shannon diversity index | 1.812954 | |
| Ecopath pedigree | 0.635 | |
| Throughput cycled (excluding detritus) | 18.00 | t/km²/year |
| Predatory cycling index | 3.808 | % of throughput without detritus |
| Throughput cycled (including detritus) | 117.7 | t/km²/year |
| Finn's cycling index | 10.67 | % of total throughput |
| Finn's mean path length | 2.991 | |
| Ascendency | 29.09 | % |
| Overhead | 70.91 | % |
| Capacity | 3853 | flowbits |

The mean transfer efficiency of the system was 4.562% . This may imply that total flow either exported or transferred to higher trophic levels by consumption. Finn’s cycling index was 10.67 % of total throughput, which indicates the ecosystem maturity. Ascendency was estimated at 29.09 % of the system capacity, implying low ascendency for the ecosystem. The system omnivory index was found to be 0.062, and the pedigree index was estimated at 0.635. The gross efficiency (actual catch/primary production) of the model was close to the global mean value (0.0003), which implied that the catch to primary production rate is in the standard value (Christensen et al., 2005) . This means fishing impact in the ecosystem is in the expected range**.** The mean trophic level of the community was calculated as 2.26.

The Lindeman Spine (Fig 3.7) demonstrated the energy flows between the main trophic levels of the food web. Trophic level II had the highest proportion of TST and biomass, excluding TL I. Respiration and flow to detritus amount decreased as trophic levels increased.

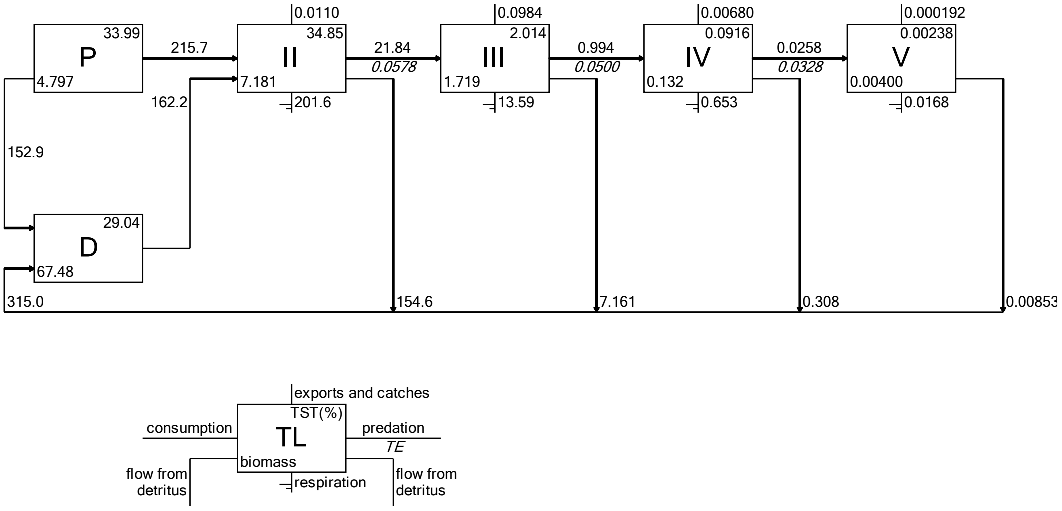


Figure 3.7 The Lindeman spine reveals trophic flows between integer trophic levels (TL). P=primary producer, D=detritus, TST=total system throughput, TE= transfer efficiency

## 3.3 Scenarios

Two scenarios were applied to the model to exhibit differences in decreasing populations of *N .randalli* on the food web interactions and ecosystem functioning. Mixed trophic impact, keystoneness index and the Lindeman spine graphs are shown in Figure 3.8.

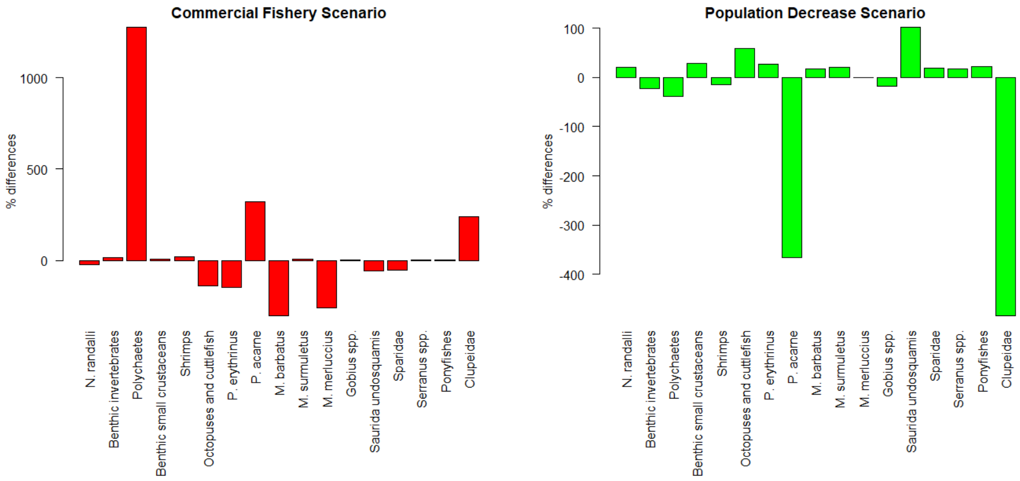


Figure 3.8 Mixed Trophic Impacts analysis of scenarios compared with the original scenario

Mixed trophic impact analyses of scenarios were compared with original scenario. Compared to commercial scenario to original scenario, *N. randalli* showed positive effect on trawling. It negatively affected some predators of polychaetes so its impact on polychaetes increased. The negative mixed trophic impact of *N. randalli* on *M. barbatus* (red mullet) was caused by indirect effects (*S. undosquamis*, being the common predator, was projected to prey on increased amounts of red mullet in the absence of *N. randalli* due to fisheries exploitation).Also, the negative mixed trophic impact of *N. randalli* on *M. merluccius* slightly intensified similarly due to indirect effects due to the increased predation of *Saurida undusquamis* on food items of *M. merluccius* such as mullets and porgies.

Compared to the decrease population scenario to the original scenario, since *Saurida undusquamis* is a predator of *P. acarne*, Clupeidae and *N. randalli*, after *N. randalli*'s population decrease, *Saurida undusquamis*'s predation pressure increased on these species.

Compared to the decrease population scenario to the original scenario, since *Saurida undusquamis* is a predator of *P. acarne* and Clupeidae, after *N. randalli*'s population decrease, Saurida undusquamis's predation pressure increased on these species.

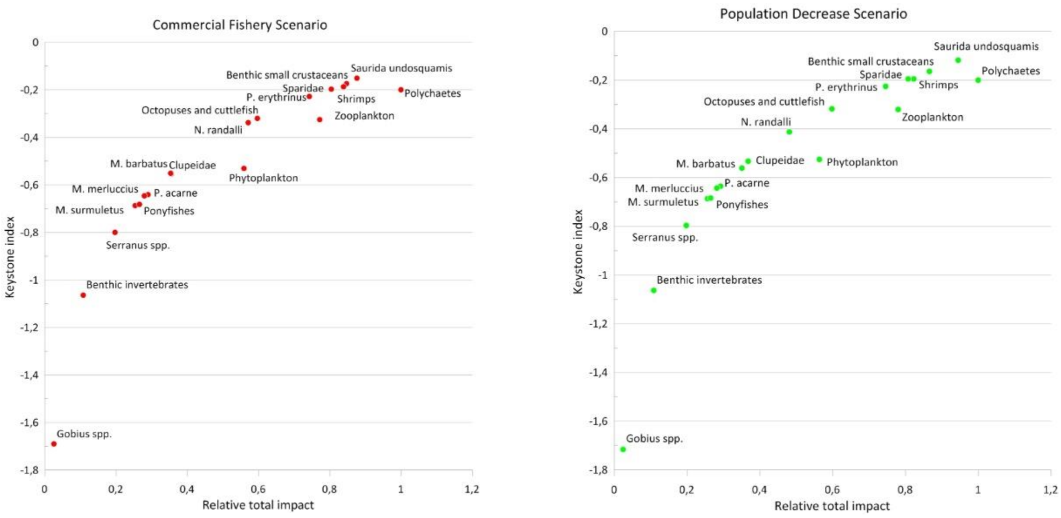


Figure 3.9 Keystoneness Index of functional groups for commercial fishery (left) and population decrease (right) scenarios

In the commercial fishery scenario, *N. randalli's* keystoneneness value decreased as *Saurida undusquamis*' keystoneness did when compared with the original scenario regarding their prey-predator relationship. When *N. randalli*'s biomass decreased, its keystone index/relative impact rate also decreased.

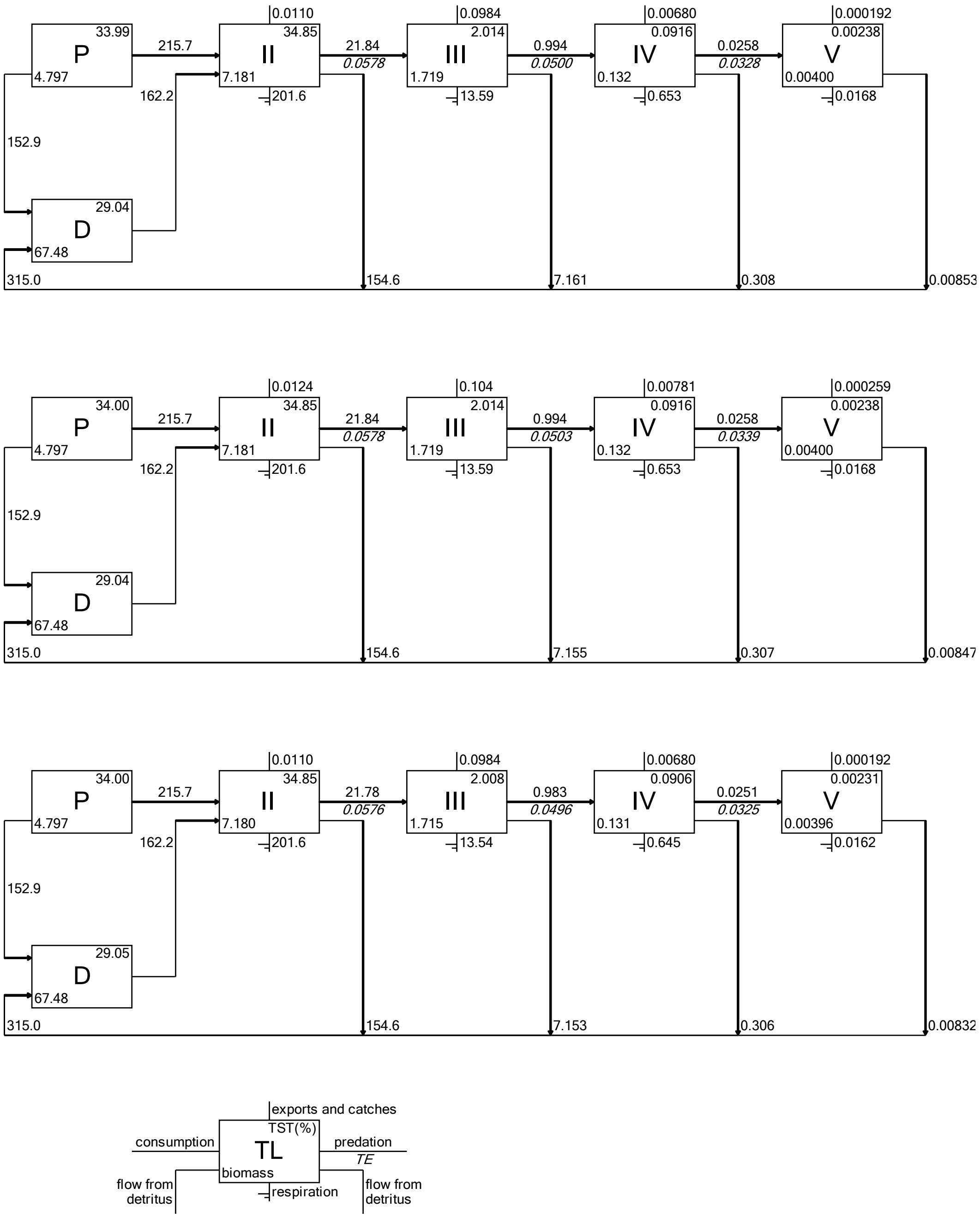


Figure 3.10 The Lindeman spines for the original model, commercial fishery and biomass decrease scenarios above to below, respectively)

Original flow data were compared to the commercial fishery and biomass decrease scenarios. The population decrease scenario showed relatively little differences in flows between III and IV with regard to the decreased population of *N. randalli*. However, there is no significant difference between the original model and the scenarios.

# CHAPTER 4

# DISCUSSION

## 4.1 Laboratory Analysis

Laboratory studies showed that approximately 50% of the stomachs that were analysed during the winter season were empty. This result may suggest that *N. randalli* has difficulty finding prey during winter. In addition, it indicates that sampling seasons are important for stomach content studies.

Laboratory studies also showed that *N. randalli*'s diet includes *Charybdis longicollis, Squilla mantis, Penaus* spp., Echinodermata species as it was in Nemipteriade families' natural habitat (Paul et al.,2018).

As Yapıcı and Filiz (2019) and Gürlek et al. (2010) suggested in their studies, this study also confirms that the subphylum Crustacea constitutes the main part of *N .randalli*'s diet. Unlike these studies, *Ophiaderma longicauda* was identified in *N. randalli*'s stomach content for the first time in the Eastern Mediterranean Sea. The presence of endoparasites in the stomach contents of *N. randalli* is remarkable. Endoparasites' impact on the *N. randalli* itself and human health should be analyzed in future studies because they can cause some infections and diseases if health constraints are not acted upon (Tessema, 2020).

## 4.2 Network Analysis, Ecological Indicators and Ecosystem Health

Food web modelling was conducted to specify the impacts of *N. randalli* in the Eastern Mediterranean ecosystem and to show the recent status of ecosystem health by comparing the current models with previous models. Model results were discussed under the following titles: functional group, ecosystem and scenarios.

There were thirteen functional groups related to *N. randalli that* were created. Biomasses of fish functional groups were calculated from the trawl results. Considering the functional groups, Ecotrophic efficiency (EE), omnivory index, mixed trophic index and keystoneness index were analyzed. Ecotrophic efficiency (EE) shows the proportion of production utilized in the food web through direct predation or fishing. When a value is near 1.0, it means that the main part of production is consumed by predators or taken by the fishery. The calculated EE values of *P. acarne* and *M. barbatus* were low, which may be associated with their underrepresentation in their predators' diets in the model.

The Omnivory index (OI) assesses the distribution of feeding interactions between trophic levels in the food web by the weighted average consumers' omnivory generally depending on the prey's trophic level. *P. acarne, M. barbatus, Gobius* spp. and Clupeidae had low OI values. The reason may be that all these functional groups consume zooplankton and polychaete, which have relatively high biomass in the model (Table A.1). *N. randalli's* omnivory index was higher than the omnivory index of other native species, indicating that *N. randalli* has wide feeding habits (generalists). Its advantage over other native species may have resulted in successful establishment of *N. randalli* in the native species' habitats because of its competitive advantage against native species such as *Pagellus erythinus* and *Pagellus acarne* (Saygu,2020). Saygu (2020) stated that *S. undusquamis* may adapt easily to the Mediterranean Sea because of its wide feeding habits (Özyurt et al,2017). Because it is a predator of *N. randalli*, it may prevent the increasing population of *N. randalli*. Additionally, Saygu (2020) suggested that *N. randalli* acted negatively on demersal fishes such as Lessepsian *Equulites klunzingeri*, in addition to *Pagellus erythrinus* and *Pagellus acarne*. Like Saygu (2020)'s results, this study also showed *N. randalli*'s negative impact on ponyfishes as their predator and *Pagellus* species as their competitor. This study found a small positive impact of *N. randalli* on shrimps, although Saygu (2020) showed a highly negative impact on shrimps. It may have resulted from the high negative effect of *N. randalli* on shrimps' main predator, *Serranus* spp..

Keystoneness index showed that *Saurida undusquamis* are key species -due to being a major predator for the majority of functional groups in the food web- with relatively low biomass and high overall impact, followed by polychaetes, benthic small crustacea and shrimps. It indicates that increasing biomass of *N. randalli* may negatively affect the ecosystem since it is the predator of polychaetes, and benthic small crustacea and shrimps. Additionally, *N. randalli* showed a higher keystone index value than some native species in the model. It shows its importance in the structuring role in the ecosystem. In the future, the increasing population of *N. randalli* may gain an advantage over native species because of the pressure of fisheries exploitation on native species. Since this model does not include all of the ecosystem function groups in the area, its keystoneness index differs from other models Saygu (2020); Coll et al. (2006); Piroddi et al. (2010) and Torres et al. (2013), which had dolphins as a key species.

Considering ecosystem level, this model does not clearly show that the food web is either affected by bottom-up or top-down control. It shows the importance of benthic-pelagic coupling due to the flow of the organisms between detritus and at TL II (Corrales et al.,2017), and the interaction of benthic demersal species in the Mediterranean Sea.

Model analysis showed that total system throughput (size of the entire system) and biomass were lower than the west and the central of the Mediterranean as expected because the eastern is more oligotrophic than other parts (Siokou-Frangou et al.,2010) but higher than Israel model (Corrales et al., 2017). Compared to the model of Saygu (2020), this model had lower biomass, TST, and a lower biodiversity index due to the lack of all ecosystem functional groups (Table 4.1). Furthermore, this model had higher net system production and total primary production/total biomass that may have resulted from the lack of predators of the highest functional group (*M. merluccius*) in the model.

Since the ratio of TPp/TR is 1 and total primary production/Total biomass is low for the mature systems, this ecosystem is not in a mature state but an early developmental stage. In other studies, conducted in the area, Tsagarakis (2010), Corrales (2017) and Saygu (2020) supported the idea that Eastern Mediterranean ecosystems are not in mature states (Table 4.1).

Furthermore, ascendency/overhead ratios were drawn to compare models in the Eastern Mediterranean (Saygu,2020; Tsagarakis, 2010). Constanza (1992) proposed three components: vigor, organization, and resilience for a healthy ecosystem. Therefore, Costanza and Mageau (1992) suggested ascendency as a combination of vigor and organization and overhead as resilience. They also proposed a balance between vigor, organization, and resilience in a healthy ecosystem. Concerning the ascendency/overhead graph, this model had a closer rate to the suggested ascendency/overhead line for a healthy ecosystem. In addition, the model has a higher ascendency value and high Finn's cycling index value compared to that of Saygu (2020). It may indicate that the study area is in a little healthier stage than Mersin bay.

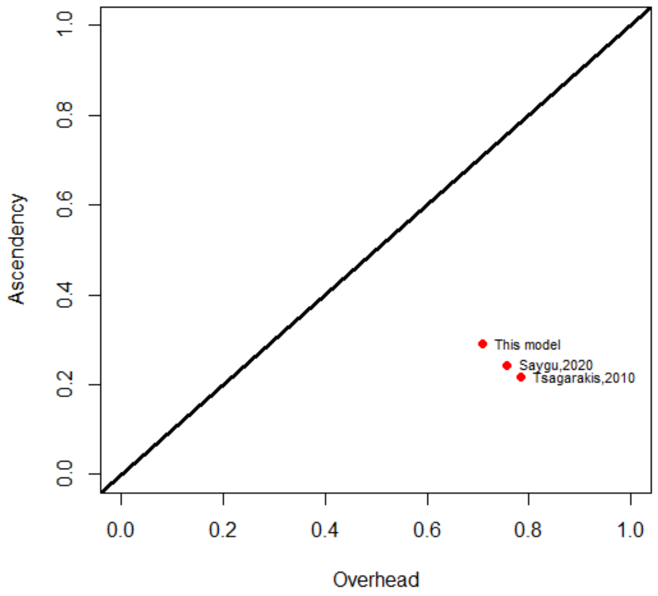


Figure 4.1 Ascendency/Overhead comparison of three Eastern Mediterranean models

Furthermore, Finn’s cycling indexes in the models of Corrales et al. (2017) and Michailidis et al. (2019) were also lower than this model. It may express that the model’s study area has  more healthy conditions compared to other study areas (Odum,1969). Its reason could be that Corrales (2017)’s study area (Israel) was closer to the Red Sea, which was exposed to more Lessepsian migration.

The model's pedigree index was ranked in the upper part of the range between 0.164-0.676 of the Ecopath models evaluated by Morissette (2007). It was also close to Saygu (2020) 's study and higher than Tsagarakis (2010) 's and Corrales (2017) 's studies. It may suggest that this model had more certain results than others for its functional groups. However, it is important to remember that this study does not include the whole ecosystem in the Eastern Mediterranean.

The depths of the model area were from 16m to 230m which differed from other models that had model areas shallower than 200m (Saygu,2020; Corrales et al., 2017). Its wide covering range of model area was an advantage to representing all functional groups which are in interactions with *N. randalli*.

The system omnivory index result was not compared with other models in the Eastern Mediterranean due to the lack of higher TLs.

Mean transfer efficiency of the model was under the average value which was reported worldwide (10%) (Pauly and Christensen, 1995). Mean transfer efficiency was lower than Saygu (2020)’s and the N. Aegean model of Tsagarakis (2010), as shown in Table 4.1. Low EE values of fish functional groups such as *M. barbatus* and *P. acarne* may be the reason for low mean transfer efficiency. This may cause the flows to go to detritus without being used in other trophic levels.

The mean trophic level of the community was lower than other models because of  the lack of higher trophic levels in the model.

The mean trophic level of catch is used to observe the overfishing risk to the ecosystem (Libralato et al.,2008). Mean trophic level of catch of the model was smaller than other models in Saygu (2020)’s study (3.29) with differences in the model structure.

Compared to the previous studies conducted in Eastern Mediterranean (Table 4.1), the total catch of the model was lower than Saygu (2020)’s and Tsagarakis (2010)’s which may result from the lack of the of discarded rate data (Pauly et al.,2014) or data absence of the small-scale fishing (Papaconstantinou and Farrugio, 2000).

Table 4.1 Summary statistics of the Eastern Mediterranean model

| | **This study** | **Saygu, (2020)** | **Corrales et al. (2017)** | **Tsagarakis et al., (2010)** | **Michailidis et al., (2019)** | **Units** |
|---|---|---|---|---|---|---|
| **Study site** | Turkey | Turkey | Israel | N. Aegean | Cyprus | |
| **Period** | 2019-2020 | 2009-2013 | 2008-2012 | 2003-2006 | 2015-2017 | |
| **Total system throughput** | 1102 | 1150 | 632 | 1976 | 841 | t km$^{-2}$ y$^{-1}$ |
| **System omnivory index (SOI)** | 0.06 | 0.16 | 0.19 | 0.18 | 0.23 | |
| **Finn's cycling index** | 10.67 | 10.09 | 5.78 | 14.6 | 9.30 | % of TST |
| **Finn's mean path length** | 2.99 | 3.12 | 2.63 | 3.63 | 3.21 | |
| **Mean transfer efficiency** | 4.56 | 9.37 | 19.0 | 17.4 | 16.93 | % |
| **TPp/TR** | 1.71 | 1.49 | 4.26 | 1.99 | 2.04 | |
| **Mean trophic level of community (excluding TL I)** | 2.26 | 2.38 | 2.60 | 2.57 | 2.66 | |
| **Total primary production/Total biomass** | 26.65 | 15.69 | 16.21 | 6.76 | 13.06 | |
| **Total catch** | 0.12 | 0.42 | 0.93 | 2.35 | 0.65 | t km$^{-2}$ y$^{-1}$ |
| **Pedigree index** | 0.64 | 0.63 | 0.54 | 0.61 | 0.62 | |

Regarding scenarios, there is no significant difference between functional groups' omnivory index. On the other hand, net system production and total primary production/total biomass increased in the population decrease scenario. This reveals that if *N. randalli* 's population did not decrease by trawling, it may cause increasing immaturity in the ecosystem. Thus, it suggests the necessity of fishery of *N. randalli*. Keystoneness index of population decrease scenario demonstrated that *N. randalli's* keystoneness impact decreased. It means that the importance of *N. randalli* in the ecosystem is decreasing. Therefore, native species are impacted less by *N. randalli* in the case of its predation or mortality rate are increased. Mean transfer efficiency did not significantly change through scenarios: (4.617) for commercial fishery and (4.529) for population decrease scenarios. 0.04 increase in mean transfer efficiency in the commercial fishery scenario. Moreover, in the commercial fishery scenario, benthic small crustacea's positive impact on the trawling increased as a result of the lack of its main predator in the system for this model.

There are some limitations of the model. For example, the model did not include discard rates which may lead to seeing the overall fishery impact on the area. The reliability of the catch data statistics is unknown (Saygu&Akoglu, 2016), causing difficulties in comparing the model with others and analyzing fishery impact. Diet data of some functional groups such as polychaetes are unknown in the Eastern Mediterranean Sea. This model did not include all functional groups in the Eastern Mediterranean because the study purpose was focusing the *N. randalli* and its possible impacts in fishery and mixed trophic impacts with different scenarios. Dynamic simulations such as Ecosim can be applied to clarify the impact of *N. randalli* in future predictions.

## 4.3 Fishery Impact

Model results showed that fisheries can benefit from *N. randalli* commercially. Because it was recently established in the Mediterranean Sea, its population can be controlled by the fishery. Otherwise, it can be settled and can cause a decrease in native species' population as their competitor or predator. A recent study by Unal et al. (2022) suggested that the amount of Lessepsian fish in Gokova Bay (Aegean Sea) was 22%, and its economic value was 9.6% in 2019. Also, *N. randalli's* percentage was 12.8% in all landings, and its economic value was 6.3%. This study also implied that *N. randalli* started to be an important Lessepsian species in the food web with its trophic level. In addition, Çinar et al. (2021) proposed that it has positive contributions to fishers' incomes.

## 4.4 Management Suggestions

After the Evergreen ship crisis in March 2021, Egyptian authorities announced that they would widen and deepen the Suez Canal (Werr,2022), which may cause more Lessepsian migration in the following years (Galil et al.,2014). Considering the Mediterranean region as a transition region with a temperate climate influenced by a colder/wetter European climate and a warmer/drier North African climate, it is a critical region for future climate changes (Giorgi, 2006). Since climate change increases the temperature in seawater, it creates a risk for native species to be replaced by Lessepsian species such as *N. randalli* in the Mediterranean Sea. The main reason is that higher sea temperatures (Red Sea: 27.88 ± 2.14°C, 19.7±0.3°C) ;(Shaltout, M.,2019; García-Monteiro, S. et al. 2022) create more favorable conditions for the Red Sea species (Turan et al.,2016; Por,2010). Increasing temperature facilitates an increase in the number of tropical species in the North Mediterranean (Raitsos et al.,2010). As this model implied the potential impact of Lessepsian species on the food web of the Eastern Mediterranean, Papapanagiotou et al. (2020) also proposed that climate change can favor thermophilic species in the Mediterranean Sea in the future.

Fisheries management is considerably complicated in the Northeastern Mediterranean like in other ecosystems of the Mediterranean Sea (Gücü 2012). However, several methods can be applied to manage the migration of *N. randalli* to the Eastern Mediterranean. As the model scenarios suggested, targeted exploitation or a bounty system can be promoted to decrease the negative impact on the native species due to decreasing competition and predation on them. Incentives of fish marketing of *N. randalli* can be another management strategy to decrease its population. Furthermore, Marine Protected Areas (MPA) can be used as a management strategy by designing and planning them to decrease Lessepsian species impacts with species-targeted removals. However there is still debate (Giakoumi et al.,2019a) about the impact of MPAs on invasive species. As stated in the biotic resistance hypothesis, high biodiversity (in MPA) is more resistant against invaders. The restoration of top predator populations and top-down regulation process in MPAs can help controlling some invasive species within the borders. For testing potentiality of MPAs, old and well-enforced MPAs can perform as mesocosm experiments by manipulating of native predators and alien species to see native predators' controlling impacts on alien species (Giakoumi et al., 2019b)

Conversely, the biotic acceptance hypothesis stated that there is a positive relationship between alien and native species (Stohlgren et al. 2006) since invasive species benefit from harvest restrictions (Klinger et al. 2006). There is no study showing the impact of *N. randalli*'s on MPAs. Therefore, inclusive management strategies that can be conducted for common invasive species are required. The important point here is that many Levantine MPAs are already dominated (concerning number of species and biomass) by invasive species of Lessepsian origin (Giakoumi et al., 2019b; Galil, 2019). However, new MPAs can be located away from the pathways of introduction and regional vector hubs with monitoring.Also, invasive populations in established MPA's can be monitored for learning options of long term control.

Moreover, fishery exploitation of native species can be reduced by selectivity of fishing gear to mitigate the advantage of *N. randalli* on the ecosystem in the Eastern Mediterranean. Updating input data information such as diet, discards, catch, and biomass is essential. For example, age and growth information is used to determine natural mortality and longevity besides demographic models such as EwE. Genetic studies should be conducted, especially on endangered or fragile native species under the threat of invasive species, to understand their genetic structure and take conservation actions accordingly. Ecosystem-Based Fisheries Management (EBFM) can be applied to managing the population of this species. EBFM is interested in the effects of fishing on the ecosystem regarding trophic interactions of target and non-target species within the food web and environmental conditions. Monitoring to revising the current plan or getting experience for a future plan can be crucial to observe differences and take decisions as soon as possible.

# CHAPTER 5

# CONCLUSION

This study is the first species-specific Ecopath model showing the impact of one of the most common Lessepsian species, *N. randalli*, on the Eastern Mediterranean Sea food web. Besides analyzing ecosystem health with network analysis, the model focused on the impact of *N. randalli* and its interaction with other species and fishery. The stomach contents of *N. randalli* were analyzed in the laboratory to give more appropriate results for the model. This study used the most recent data to describe the current state of the ecosystem functioning and structure compared to other models in the study area. According to the study findings, *N. randalli's* increasing population in the Eastern Mediterranean negatively affects the native species. According to the study findings, *N. randalli's* increasing population in the Eastern Mediterranean negatively affects the native species. Also, *N. randalli* can be advantageous over native species and replace their habitat due to fishing pressure on them. Results also showed that fisheries can benefit from *N. randalli* commercially, as literature supports its positive impact on the fishery (Çinar et al., 2021). Created scenarios in the model presented the requirement of the fishery of *N. randalli* to manage its stocks. Ecosystem characteristics are similar to other Eastern Mediterranean ecosystems. They are in the early developmental stage of maturity. Additionally, in laboratory studies, *Ophiaderma longicauda* was identified in *N. randalli'* s stomach content for the first time in the Eastern Mediterranean Sea.

To sum up, further local studies about benthic invertebrates, polychaetes and benthic crustaceans, shrimps' diets and official statistics of catch data locations and separate statistics for the species such as *N. randalli* are needed to get more accurate results for the models in the Eastern Mediterranean Sea. Future work should include temporal data to compare differences in the species' population and impacts in years. Targeted exploitation could be implemented to save fishery exploitation of native species and to decrease the population of *N. randalli*. MPA designs to mitigate and control the population of Lessepsian species, including *N. randalli* and marketing incentives for *N. randalli* can help to manage the negative impact of *N. randalli* on the Eastern Mediterranean ecosystem.

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## APPENDICES

## A. Input data for the balanced model

Table A.1 References of input data for the balanced model

| **Functional Groups** | **Biomass References** | Biomass | **P/B References** | | **Q/B References** | | **Diet References** |
|---|---|---|---|---|---|---|---|
| Phytoplankton | Acker and Leptoukh (2007) | 4.797 | Saygu (2018) | 76.85 | | | |
| Zooplankton | Yılmaz and Besiktepe (2010) | 3.338 | Saygu (2018) | 30.42 | Saygu (2018) [P/Q assumption] | 92.18 | Zervoudaki et al., (2007);(Båmstedt and Karlson, 1998; Pauly et al., 2009) |
| *Nemipterus randalli* | Trawl | 0.037 | Ergüden et al (2010) | 1.42 | Trawl | 15.39 | Trawl |
| Benthic invertebrates | Trawl | 0.055 | Brey,2012 | 0.94 | Saygu(2018) | 3.927 | Tgasarakis et al,2010) |
| Polychaetes | Ergev (2002) | 1.620 | Saygu (2018) | 3.61 | Saygu (2018) | 24.06 | Fauchald and Jumars, (1979) |

Table A.1 (continued)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Benthic small crustaceans | Trawl | 0.070 | Saygu (2018) | 6.32 | Saygu (2018) | 39.59 | Stasolla et al. (2015) charybdis |
| Shrimps | Trawl | 0.243 | Arce (2006) | 3.18 | calculated by EE | 11.43 | Benennal et al. (2020) |
| Octopuses and Cuttlefish | Trawl | 0.051 | Brey (2012) | 1.61 | Iglesias et al. 1996 ; Quintela and Andrade (2002) | 4.644 | Martínez-Baena et al. (2016) |
| *Pagellus erythrinus* | Trawl | 0.140 | Çiçek et al. (2012) | 0.97 | Metin (2011) | 10.63 | Šantić et al. (2011) |
| *Pagellus acarne* | Trawl | 0.230 | Tsikliras and Stergious (2015) | 2.395 | Soykan et al. (2015) | 12.55 | İlhan (2018) |
| *Mullus barbatus* | Trawl | 0.500 | Cicek(2015) | 1.39 | Celik and Torcu (2000) | 8.887 | Mahmoud et al. (2017) |
| *Mullus surmuletus* | Trawl | 0.013 | Mehanna(2009) | 1.16 | Kousteni et al. (2019) | 7.884 | Mahmoud et al. (2017), Labropoulou (1997) |
| *M. merluccius* | Trawl | 0.021 | Soykan et al. (2015) | 2.41 | Soykan et al. (2015) | 6.561 | Cartes et al. (2004) |

Table A.1 (continued)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Gobius sp | Trawl | 0.002 | (Kırdar, F., İşmen, A., 2018) | 1.33 | Filiz and Togulga (2009) | 11.83 | Filiz and Togulga (2009) |
| *Saurida undosquamis* | Trawl | 0.083 | Bilecenoğlu (2010) | 1.76 | Mehanna et al. (2014) | 7.569 | Ozyurt et al. (2017) |
| Sparidae | Trawl | 0.418 | Vidalis and Tsimenidis(1996) | 0.89 | Soykan et al(2015),Koc et al(2002),Benchalel and Kara(2013),Türkmen and Akyurt(2003),Elawad et al(2017),Apostolidis and Stergiou(2014),Yeltan et al(2003) | 9.9 | Maremie and Mohammad (2015),(Altın et al,2015),(Hamida et al ,2015),Chaouch et al(2013) |
| Serranus spp. | Trawl | 0.012 | Dulcˇic´ et al (2007),(Rachedi M, Dahel A.T., 2019) | 1.70 | İlhan et al (2010), Soykan et al. (2013) | 12.85 | Yapıcı et al. (2012) |

Table A.1 (continued)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Equulites elongatus* | Trawl | 0.408 | Ozutok and Avsar (2004) | 7.20 | Fishbase(no reference) | 20.84 | Acharya et al. (2016) |
| Clupeidae | Trawl | 0.022 | Salem, M., El_Aiatt, A.A. Ameran, M, (2010);Wassef, E., Ezzat, A., Hashem, T., Faltas S., (1985);Erdoğan, Z., Torcu Koç, H., Gicili, S., Ulunehir, G., (2010) | 1.36 | Padilla(1991), Akyol et al(19969,Mater et al(2003),FAO(1982) | 13.78 | Bayhan et al (2015) |

Table A.2 Original diet composition data of functional groups

| **No** | **Prey \ predator** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
|---|---|---|---|---|---|---|---|---|
| **1** | **Phytoplankton** | 0.700 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **2** | **Zooplankton** | 0.050 | 0.000 | 0.000 | 0.000 | 0.000 | 0.026 | 0.000 |
| **3** | ***Nemipterus randalli*** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **4** | **Benthic invertebrates** | 0.000 | 0.009 | 0.032 | 0.000 | 0.010 | 0.009 | 0.000 |
| **5** | **Polychaetes** | 0.000 | 0.000 | 0.021 | 0.056 | 0.010 | 0.164 | 0.000 |
| **6** | **Benthic small crustaceans** | 0.000 | 0.548 | 0.000 | 0.000 | 0.080 | 0.035 | 0.000 |
| **7** | **Shrimps** | 0.000 | 0.091 | 0.000 | 0.000 | 0.010 | 0.000 | 0.001 |
| **8** | **Octopuses and Cuttlefish** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.008 |
| **9** | ***Pagellus erythrinus*** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.007 |
| **10** | ***Pagellus acarne*** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **11** | ***Mullus barbatus*** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **12** | ***Mullus surmuletus*** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **13** | ***Merluccius merluccius*** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **14** | ***Gobius* spp.** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **15** | ***Saurida undosquamis*** | 0.000 | 0.020 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **16** | **Sparidae** | 0.000 | 0.015 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **17** | ***Serranus* spp.** | 0.000 | 0.086 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **18** | **Ponyfishes** | 0.000 | 0.035 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **19** | **Clupeidae** | 0.000 | 0.170 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **20** | **Detritus** | 0.250 | 0.195 | 0.947 | 0.944 | 0.890 | 0.766 | 0.983 |
|  | Import | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
|  | Sum | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |

Table A.2 (continued)

| **No** | **Prey \ predator** | **9** | **10** | **11** | **12** | **13** | **14** | **15** |
|---|---|---|---|---|---|---|---|---|
| **1** | **Phytoplankton** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **2** | **Zooplankton** | 0.000 | 0.135 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **3** | ***Nemipterus randalli*** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.010 |
| **4** | **Benthic invertebrates** | 0.015 | 0.103 | 0.068 | 0.063 | 0.000 | 0.000 | 0.001 |
| **5** | **Polychaetes** | 0.107 | 0.145 | 0.192 | 0.073 | 0.000 | 0.018 | 0.000 |
| **6** | **Benthic small crustaceans** | 0.058 | 0.227 | 0.128 | 0.161 | 0.000 | 0.000 | 0.000 |
| **7** | **Shrimps** | 0.102 | 0.000 | 0.000 | 0.000 | 0.012 | 0.000 | 0.005 |
| **8** | **Octopuses and Cuttlefish** | 0.023 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 |
| **9** | ***Pagellus erythrinus*** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.035 |
| **10** | ***Pagellus acarne*** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.010 |
| **11** | ***Mullus barbatus*** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.003 |
| **12** | ***Mullus surmuletus*** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.010 |
| **13** | ***Merluccius merluccius*** | 0.000 | 0.000 | 0.000 | 0.000 | 0.326 | 0.000 | 0.000 |
| **14** | ***Gobius* spp.** | 0.024 | 0.000 | 0.000 | 0.053 | 0.000 | 0.000 | 0.000 |
| **15** | ***Saurida undosquamis*** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.008 |
| **16** | **Sparidae** | 0.013 | 0.000 | 0.000 | 0.000 | 0.133 | 0.000 | 0.034 |
| **17** | ***Serranus* spp.** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.028 |
| **18** | **Ponyfishes** | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.031 |
| **19** | **Clupeidae** | 0.000 | 0.000 | 0.000 | 0.000 | 0.277 | 0.000 | 0.478 |
| **20** | **Detritus** | 0.658 | 0.390 | 0.612 | 0.650 | 0.529 | 0.982 | 0.823 |
|  | Import | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
|  | Sum | 1.000 | 1.000 | 1.000 | 1.000 | 1.001 | 1.000 | 1.000 |

Table A.2 (continued)

| **No** | **Prey \ predator** | **16** | **17** | **18** | **19** |
|---|---|---|---|---|---|
| **1** | **Phytoplankton** | 0.000 | 0.000 | 0.020 | 0.000 |
| **2** | **Zooplankton** | 0.012 | 0.048 | 0.408 | 0.261 |
| **3** | ***Nemipterus randalli*** | 0.000 | 0.000 | 0.000 | 0.000 |
| **4** | **Benthic invertebrates** | 0.020 | 0.000 | 0.000 | 0.000 |
| **5** | **Polychaetes** | 0.151 | 0.000 | 0.010 | 0.005 |
| **6** | **Benthic small crustaceans** | 0.010 | 0.293 | 0.000 | 0.012 |
| **7** | **Shrimps** | 0.135 | 0.603 | 0.000 | 0.000 |
| **8** | **Octopuses and Cuttlefish** | 0.009 | 0.000 | 0.000 | 0.000 |
| **9** | ***Pagellus erythrinus*** | 0.000 | 0.000 | 0.000 | 0.000 |
| **10** | ***Pagellus acarne*** | 0.000 | 0.000 | 0.000 | 0.000 |
| **11** | ***Mullus barbatus*** | 0.002 | 0.000 | 0.000 | 0.000 |
| **12** | ***Mullus surmuletus*** | 0.000 | 0.000 | 0.000 | 0.000 |
| **13** | ***Merluccius merluccius*** | 0.000 | 0.000 | 0.000 | 0.000 |
| **14** | ***Gobius* spp.** | 0.000 | 0.049 | 0.000 | 0.000 |
| **15** | ***Saurida undosquamis*** | 0.000 | 0.000 | 0.000 | 0.000 |
| **16** | **Sparidae** | 0.000 | 0.000 | 0.000 | 0.000 |
| **17** | ***Serranus* spp.** | 0.000 | 0.000 | 0.000 | 0.000 |
| **18** | **Ponyfishes** | 0.000 | 0.000 | 0.000 | 0.000 |
| **19** | **Clupeidae** | 0.000 | 0.000 | 0.000 | 0.000 |
| **20** | **Detritus** | 0.662 | 0.007 | 0.563 | 0.722 |
|  | Import | 0.000 | 0.000 | 0.000 | 0.000 |
|  | Sum | 1.000 | 1.000 | 1.000 | 1.000 |

## B. Biomass data

Table B.1 Original Biomass and Balanced Biomass for Model

| **Functional Groups** | **Original** | **Balanced** |
|---|---|---|
| *N. randalli* | 0.037393 | 0.0199 |
| Benthic invertebrates | 0.054563 | 0.179 |
| Benthic small crustaceans | 0.069549 | 0.269 |
| Shrimps | 0.243238 | 0.55 |
| Octopuses and cuttlefish | 0.101919 | 0.0464 |
| *P. erythrinus* | 0.139531 | 0.156 |
| *P. acarne* | 0.230229 | 0.23 |
| *M. barbatus* | 0.499779 | 0.328 |
| *M. surmuletus* | 0.013064 | 0.0126 |
| *M. merluccius* | 0.020867 | 0.0188 |
| *Gobius* spp. | 0.002252 | 0.00806 |
| *Saurida undosquamis* | 0.082912 | 0.049 |
| Sparidae | 0.418494 | 0.263 |
| *Serranus* spp. | 0.012337 | 0.0136 |
| Ponyfishes | 0.408203 | 0.374 |
| Clupeidae | 0.022334 | 0.171 |