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# Using Remote Sensing and GIS for Monitoring and Predicting Potential Fishing Zones of *Sardinella aurita* Fisheries along the North Sinai Coastal Zone, Egypt

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## ABSTRACT

The round sardinella, *Sardinella aurita*, is the most important species in the North Sinai fisheries; it represents about 85 % of the total catch in the North Sinai fisheries, yet the fishing activities are still based on traditional methods, like gathering information from fellow fishermen. The fishing grounds constantly change due to environmental factors; therefore, determining the potential fishing zones (PFZs) must depend on effective and advanced techniques to monitor the optimal (PFZs) for *Sardinella aurita* along the North Sinai coastal zone. This study integrated the daily Sentinel-3 satellite's remotely sensed data, advanced digital imagery processing techniques, and fish yield data obtained from the General Authority for Fish Resources Development (GAFRD) for *Sardinella aurita* in the North Sinai fisheries during 2021 to build a suitable model for determining, monitoring, and predicting the other optimal (PFZs) for *Sardinella aurita* along the North Sinai coastal zone. The results confirmed that, regarding the total catch of *Sardinella aurita* in 2021, the highest catch reached 73, 68, and 47 tons in April, December, and November, respectively, while the lowest catch reached 6 tons in January. The predicted PFZs resulting from the model are estimated to be 7 times more than the fishing grounds where fishermen currently fish. Moreover, the results confirmed the strong linkage between *Sardinella aurita* abundance and chlorophyll-a (Chl-a) concentration with sea surface temperature (SST). This study highlighted the importance of using remotely sensed data to help increase the national income from the fisheries sector by determining and predicting new fishing zones.

## INTRODUCTION

The Egyptian Mediterranean coastline is one of the longest in North Africa; it extends about 1050km from EL-Salloum in the west to El-Arish in the east. Although the Egyptian Mediterranean coast is economically significant, with substantial investments in various industries, including marine fisheries, this vast area's mean annual fish production was at most 60 thousand tons **(GAFRD, 2000 - 2020)**.

The Egyptian Mediterranean fisheries are the largest fishing area in the Egyptian national fisheries **(El-Karashily & Saleh, 1986)**; the Egyptian Mediterranean continental shelf is about 31,000km$^2$, and contains an inshore fishing area of 29,160km$^2$ **(Aly *et al.*,**

**2019)**. Commercial fisheries are a vital source of animal protein and national income in Egypt **(Lucchetti *et al.*, 2016)**. However, the commercial catch from the Egyptian Mediterranean fisheries showed that its annual production is too low, with a declining trend in recent years **(Hafiz, 1985)**.

Such decrease in these fisheries yields was mainly due to the increase in the fishing fleet, where 63% of the Egyptian marine fishing fleet is working in the Mediterranean Sea water **(Hafiz, 1985)**, the substantial increase in marine pollution along the Egyptian Mediterranean coast in the last decades is due to environmental factors that cause changes in fishing grounds and fishing production, as well as the fishing regulations established to manage the national Egyptian fisheries. Moreover, the traditional methods that are always used by fishermen in their fishing activities are based on repeated experiences and gathered information from fellow fishermen. Therefore, fisheries yields are less than optimal because of the mis-determination of the optimal potential fishing grounds by fishermen **(Emara *et al.*, 1992; Marchal *et al.*, 2002; El Deeb *et al.*, 2007; Fathy *et al.*, 2012; Shreadah *et al.*, 2014; Samy-Kamal, 2020)**.

Generally, the fishing grounds along the Egyptian Mediterranean coast are divided into four regions namely: the Western region "Matrouh, EL-Max and Alexandria, Abu-Qir, EL-Miaadiya, and Rasheed); the Nile Delta region, the Damietta region, and the Eastern region "Port Said and EL-Arish" **(Mehanna & Haggag, 2010; GAFRD, 2017)**.

Although the North Sinai coastline extends about 220km **(Hereher, 2013; Omran & Negm, 2020)**, about one-fifth of the Egyptian Mediterranean coastline, the North Sinai fishing grounds yields constitute only 6% of the total Egyptian Mediterranean fisheries yields **(GAFRD, 2017)**. Even though this area has a high depth and a high biodiversity level, the fleet vessels exploit inshore fishing grounds only **(Papaconstantinou & Farrugio, 2000)** due to the traditional experiential methods, the fishermen still use to determine the fishing grounds; therefore, the North Sinai fisheries yields are less than optimal because of the mis-determination of the optimal fishing grounds.

The fishing grounds are constantly changing due to several environmental factors. Fish choose a more proper habitat for feeding, reproduction and migration **(Palacios *et al.*, 2006)**. Several dynamic oceanographic factors influence fish habitats, serve as controlling attributes to fisheries, and greatly influence fish abundance and distribution in fishing grounds **(Zainuddin, 2007)**.

The biological and physical processes in the marine ecosystem are diverse, but chlorophyll-a (Chl-a) and sea surface temperature (SST) are among the most critical oceanographic parameters influencing fisheries **(Solanki *et al.*, 2003)**. Chl-a serves as a key indicator of marine ecosystem productivity and is closely linked to phytoplankton biomass, which in turn is strongly correlated with fish production **(Solanki *et al.*, 2003)**. Additionally, SST is a vital marine physical index that affects marine life and plays a crucial role in regulating the growth and distribution of phytoplankton **(Tang *et al.*, 2003)**.

The integration between Chl-a as the primary biological production parameter and SST as the primary physical parameter for fish distribution was found to be effective in monitoring fishing grounds and determining the Potential Fishing Zones (PFZs). These complications represented a significant challenge for fishermen in locating the appropriate fishing grounds using traditional methods **(Solanki *et al.*, 2003)**. Therefore, determining the PFZs using advanced technologies based on remotely sensed data becomes necessary.

Satellite sensors provide a means for access to the entire globe with a unique ability to carry out regularly repeated monitoring for specific regions, with high accuracy and more cost-effective than traditional fieldwork **(Mumby *et al.*, 1999; Benfield *et al.*, 2007)**; moreover, satellite remote sensing has been globally used in detecting and monitoring the PFZs using specific environmental parameters (Chl-a, SST, and productivity data), as discussed in a body of literature **(Solanki *et al.*, 2003; Lanz *et al.*, 2009; Zainuddin & Jamal, 2009; Mustapha *et al.*, 2010; Zainuddin, 2011; Ali *et al.*, 2022)**.

Furthermore, many approaches have been introduced globally to detect and monitor PFZs using many satellite sensors and different remotely sensed data, as previously discussed in many studies **(Mansor *et al.*, 2001; Solanki *et al.*, 2003;Tang *et al.*, 2003; Balaguru *et al.*, 2014; Rueda-Roa *et al.*, 2017; Rintaka & Susilo, 2018; Ali *et al.*, 2022)**. Additionally, the suitability models proved more effective in predicting the spatial distribution of fisheries by defining the suitable bio-environment conditions of particular species fishing grounds **(Hirzel *et al.*, 2006; Jędrzejewski *et al.*, 2008; Zorn *et al.*, 2012)**.

The round sardinella, *Sardinella aurita*, is the first in importance in the North Sinai fisheries since it represented about 86% of the total catch in the North Sinai fisheries and contributed to approximately 30% of the total catch in the Egyptian Mediterranean fisheries **(EL-Aiatt, 2004)**.

**Mehanna and Salem (2011)** studied the monthly population dynamics of *Sardinella aurita* on El-Arish coast in 2008 and 2009. Another study conducted by **Ali *et al.* (2022)** considered the efficiency of satellites for detecting *Sardinella aurita* PFZs along the Egyptian Mediterranean coast. However, the last study didn't explain or detect the actual fishing grounds along the Egyptian Mediterranean coast.

Thus, the present study aimed to monitor and predict the optimal Potential Fishing Zones (PFZs) for *Sardinella aurita* along the North Sinai coastal zone by integrating the daily Sentinel-3 satellite data with Geographic Information System (GIS) modeling techniques and fish yield data obtained from GAFRD for *Sardinella aurita* in the North Sinai fisheries during 2021 to build a suitable model for monitor and predict *Sardinella aurita*.

## MATERIALS AND METHODS

### 1. Study area

The North Sinai Governorate is located north of the Sinai Peninsula, northeast of Egypt. The North Sinai coastal zone extends for about 220km along the Mediterranean Sea, from Port Said in the west to the Egyptian border at Rafah in the east. The study area is located between longitudes 32° 33' E and 34° 22' E, and latitudes 31° 04' N and 31° 34' N, extending offshore for almost 70km in the Mediterranean Sea, with about 4677.3km$^2$ of area, as shown in Fig. (1).

## 2. Data acquisition

### *2.1. Satellite data*

The present study employed daily imageries of Level-2 satellite data from the Sentinel-3 satellite for each parameter of Chl-a and SST throughout 2021. The chlorophyll-a (Chl-a) concentration was derived from the ocean and land color instrument (OLCI) with 300m spatial resolution. In contrast, the sea surface temperature (SST) data were derived from the sea and land surface temperature instrument (SLSTR), with 1km spatial resolution. The Sentinel-3 data were obtained from the Copernicus Open Access Hub at Level 2 (https://dataspace.copernicus.eu/). These data were acquired throughout 2021 to determine and predict the optimal Potential Fishing Zones (PFZs) for *Sardinella aurita* along the North Sinai coastal zone. Given that the Sentinel-3-based integration of chlorophyll-a (Chl-a) and sea surface temperature (SST) for potential fishing zones (PFZs) detection has yielded highly accurate results **(Ali *et al.*, 2022)**, it is evident that PFZ detection is closely tied to the integration of Chl-a and SST. The daily Chl-a and SST data were averaged monthly and georeferenced using the SNAP toolbox software version 10.0.0 for Windows. Data cropping to the study area, modeling, and post-processing were carried out using ArcGIS software version 10.4 for Windows.

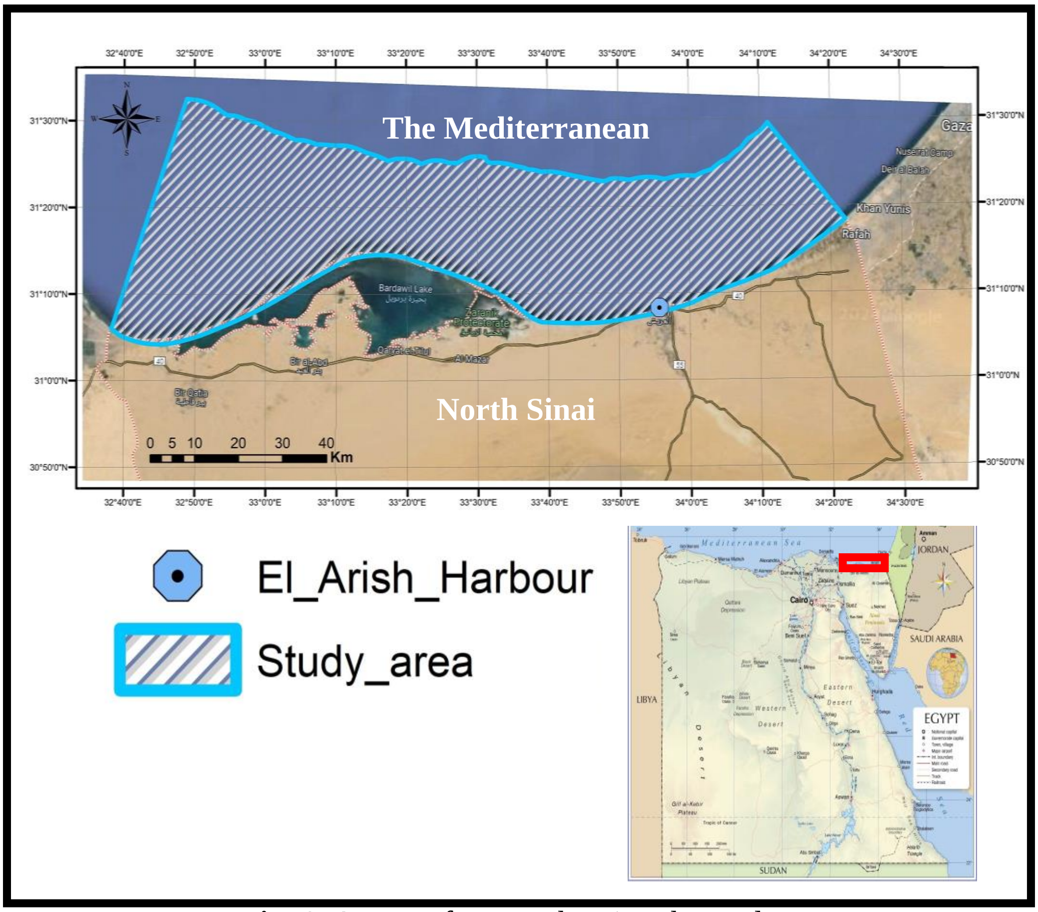


**Fig. 1.** A map of Egypt showing the study area

### *2.2. Field survey*

Four field surveys were undertaken in El-Arish fishing harbor in March, June, September, and December 2021. Fishermen were interviewed and filled out a pre-designed questionnaire to collect all required data about different fleet types, *Sardinella aurita* catch, and the fishing grounds locations, where fishermen are engaged in their fishing activities. The actual fishing grounds extend from the west side of El-Arish fishing harbor to the Bardawil Lake Strait No. I, with about 560km$^2$ with 63 catch points. Fishing operations mainly used trammel nets and purse seines nets.

### *2.3. Ancillary data*

The GAFRD published The Fish Statistics Yearbook in Egypt in 2021 via the Central Agency for Public and Mobilization and Statistics (CAPMAS) website, which provided the Egyptian Mediterranean monthly fish production statistical data. The monthly quantities of *Sardinella aurita* in the study area were used to create a reliable database for *Sardinella aurita* catch, integrate it with the field survey outputs, and correlate it with *Sardinella aurita in-situ* mapping. The North Sinai monthly production and quantities of *Sardinella aurita* are shown in Table (1).

## 3. Model suitability for *Sardinella aurita*

Suitability models have proven highly efficient in predicting the distribution of specific species based on their suitable environmental conditions **(Hirzel *et al.*, 2006; Jędrzejewski *et al.*, 2008; Zorn *et al.*, 2012)**. The suitable values for *Sardinella aurita* were determined at 0.2 – 20mg/ m$^3$ for Chl-a concentration and at 22 – 28.5°C for SST values. The suitability values for *Sardinella aurita* were determined according to different approaches that defined suitable Chl-a and SST values for *Sardinella aurita* **(Agenbag *et al.*, 2003; Solanki *et al.*, 2003; Kripa *et al.*, 2014)**.

**Table 1.** The monthly production (Ton) of *Sardinella aurita* from the North Sinai coastal zone during 2021

| Month | Jan | Feb | Mar | Apr | May | June | July | Aug | Sep | Oct | Nov | Dec | total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Sardinella* sp. catch (ton)** | 6 | 0 | 0 | 73 | 34 | 26 | 24 | 25 | 24 | 23 | 47 | 68 | 350 |

Source: Author’s calculations using **GAFRD (2021)** data of **CAPMAS (2023**)

## 4. Mapping and modeling the potential fishing zones for *Sardinella aurita*

The integration of suitable environmental conditions for *Sardinella aurita*, including chlorophyll-a (Chl-a) and sea surface temperature (SST), with field data from fishermen's questionnaires and fish production statistics obtained from the General Authority for Fish Resources Development (GAFRD), facilitated the mapping of actual fishing zones for *Sardinella aurita*. The resulting fishing zones were then converted into a spatial geographic layer for post-processing and analysis. Using the ArcGIS modeler tool, a model was built to detect other regions with similar environmental conditions for *Sardinella aurita*. A similar potential fishing zones model has been provided and validated by **Ali *et al.* (2022)**.

## RESULTS AND DISCUSSION

### 1. The monthly total catch of *Sardinella aurita*

In the present study, the monthly catch of *Sardinella aurita* along the North Sinai fisheries from January to December 2021 showed that fishing operations extended almost throughout the year, except the period from January 15th to March 31st, 2021, as a seasonal closure for fishing, based on an administrative decision by GAFRD. The monthly catch of *Sardinella aurita* reached the highest production in April, reaching 73 tons, then decreased gradually until it reached less production in October, reaching 23 tons. After that, the monthly production increased again, reaching 47 and 68 tons in November and December, respectively, as shown in Fig. (2).

Regarding seasonal fishing closures, the present study confirmed and matched what was mentioned by **Samy-Kamal (2015, 2020)** that the seasonal closure during the spawning seasons (each year) is an effective management strategy for the Egyptian fisheries and stops overfishing. Moreover, regarding the monthly catch variations of *Sardinella aurita* in North Sinai fisheries, the present results agree with what was stated by **Mehanna and Salem (2011)** that the fishing in the Egyptian Mediterranean east water, particularly El-Arish water, runs all over the year. The monthly catch varies based on water surface temperature and other environmental parameters like Chl-a concentrations and relatively high salinities. Moreover, the monthly highest catch of *Sardinella aurita* in North Sinai fisheries was recorded during the winter months, while the monthly lowest catch was obtained during the summer months **(Faltas, 1983)**.

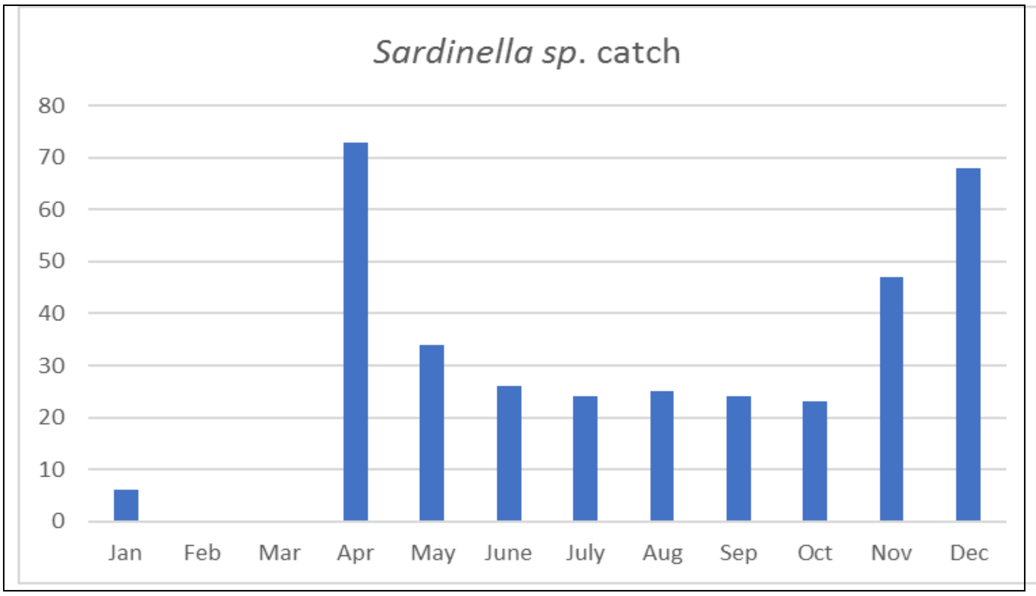


**Fig. 2.** The monthly total catch (Ton) of *Sardinella aurita* in 2021

### 2. The monthly variations of targeted environmental parameters (Chl-a and SST)

#### *2.1. The monthly variations of chlorophyll-a (Chl-a) concentrations*

In this study, the average monthly variations of Chl-a concentrations obtained from Sentinel-3 data during 2021 months showed that the Chl-a concentrations were highly variated and distributed along and near the coast, but the monthly average values vary wildly. However, the highest maximum and the highest minimum values of Chl-a concentration were

21.6 and 2.4mg/ $m^3$, respectively, and were recorded in March, while the lowest maximum and the lowest minimum values of Chl-a concentration were 7.5 and 1.01mg/ $m^3$, respectively, and were recorded in December, as shown in Table (2).

A body of literature confirmed that the higher the Chl-a values in water, the more fertile the water is because Chl-a is the primary food source for fish **(Daris *et al.*, 2021; Putri *et al.*, 2021)**. The present results coincid with those of the previous studies in the region, which confirmed that North Sinai Mediterranean waters have high depth and sufficient level of biological productivity; therefore, the fishing runs all over the year **(EL-Aiatt, 2004; Mehanna & Salem, 2011)**. However, fishing grounds are not only determined by the Chl-a values and distribution in water since the SST is a marine physical ecosystem index that directly impacts marine living organisms and explicitly controls phytoplankton growth and fish distribution **(Tang *et al.*, 2003; Kassi *et al.*, 2018)**.

***2.2. The monthly variations of sea surface temperature (SST)***

In this study, the average monthly variations of SST obtained from Sentinel-3 data during 2021 months showed that the highest maximum and minimum values of SST were 31.5 and 29°C, respectively, and were recorded in August, while the lowest maximum and minimum values of SST were 19 and 12°C, respectively, and were recorded in February, as shown in Table (2).

The SST variations enhance the upwelling movement, which is essential in determining fishing grounds since fish in the region migrate from cooler to warmer grounds; thus, (SST) controls fish presence and distribution **(Kassi *et al.*, 2018; Paillin *et al.*, 2020)**. The present results agreed with a recent study by **Ali *et al.* (2022)** in the Mediterranean Sea, where the highest SST was recorded in August, while the lowest SST was recorded in winter months; however, there are little variations in SST values between the two studies, which could be due to the large scale that **Ali *et al.* (2022)** were working on the Mediterranean Sea that leads to some variations when producing the average SST of that large area, while the present study is targeting the North Sinai coastal zone (which is much smaller).

**Table 2.** Data of the monthly variations (minimum and maximum of chlorophyll-a (mg/m3) and sea surface temperature (ºC)

| Month | | Chl-a (mg/m$^3$) | SST (° C) |
|---|---|---|---|
| **January** | Min | 1.8 | 12.6 |
| | Max | 12.4 | 21.5 |
| **February** | Min | 1.1 | 12 |
| | Max | 9.3 | 19 |
| **March** | Min | 2.4 | 15 |
| | Max | 21.6 | 24 |
| **April** | Min | 1.2 | 17 |
| | Max | 8 | 24 |
| **May** | Min | 1.1 | 20 |
| | Max | 8.9 | 27 |
| **June** | Min | 1.2 | 25 |
| | Max | 9.8 | 28 |
| **July** | Min | 1.2 | 28 |

| | | | |
|---|---|---|---|
| | Max | 9.2 | 31 |
| **August** | Min | 1.1 | 29 |
| | Max | 11.3 | 31.5 |
| **September** | Min | 1.2 | 27 |
| | Max | 14 | 29 |
| **October** | Min | 1.2 | 23 |
| | Max | 9.4 | 28 |
| **November** | Min | 1.6 | 19 |
| | Max | 8.1 | 27 |
| **December** | Min | 1.01 | 12 |
| | Max | 7.5 | 26 |

**Chl-a**: Chlorophyll-a; **SST**: Sea Surface Temperature

### 3. The monthly spatial distribution of *Sardinella aurita* potential fishing zones

In this study, the monthly potential fishing zones maps of *Sardinella aurita* fishing grounds were produced based on the environmental parameters (Chl-a and SST) products obtained from Sentinel-3 satellite data along the North Sinai coastal zone in 2021 using the Arc GIS model, combined with the field survey data outcomes, and the monthly quantities of *Sardinella aurita* in the study area obtained from the Fish Statistics Yearbook in Egypt published by GAFRD.

The monthly potential fishing zones (PFZs) of *Sardinella aurita* are significantly determined and affected by the suitable values of Chl-a and SST in the fishing grounds with average stable salinity, where the suitable values for *Sardinella aurita* were determined and defined at 0.2 – 20mg/ $m^3$ for Chl-a concentration and at 22 – 28.5°C for SST values. This result was confirmed in previous studies that studied the correlation between *Sardinella aurita* fishing ground and environmental parameters such as Chl-a and SST. They proved that there is a positive correlation between *Sardinella aurita* distribution at different life stages and Chl-a and SST environmental parameters **(Cury *et al.*, 2000; Agenbag *et al.*, 2003; Solanki *et al.*, 2003; Kripa *et al.*, 2014; Baali *et al.*, 2019; Ali *et al.*, 2022)**.

In the present study, the monthly PFZ areas for *Sardinella aurita* were greatly varied. The maximum areas of potential fishing for *Sardinella aurita* reached 3888, 3840, and 3620$Km^2$ in April, December and November, respectively; since the SST values were suitable for *Sardinella aurita* abundance. While, the minimum area of potential fishing areas for *Sardinella aurita* reached 1120$Km^2$ in January, as the SST values were lower than the suitable values for *Sardinella aurita* abundance. The Chl-a concentrations were suitable for *Sardinella aurita* abundance throughout the year.

The results in Table (3) show the monthly actual and predicted values for *Sardinella aurita* catch and fishing ground areas in 2021, while mapping of the monthly actual and potential fishing grounds are illustrated in Fig. (3).

**Table 3.** The monthly actual and predicted values for *Sardinella aurita* catch (Ton) and fishing ground areas ($Km^2$) in 2021

| Month | Actual | | Predicted | |
|---|---|---|---|---|
| | Catch (ton) | Area ($Km^2$) | Catch (ton) | Area ($Km^2$) |
| **January** | 6 | 560 | 12 | 1120 |
| **February** | 0 | 560 | 0 | 1880 |
| **March** | 0 | 560 | 0 | 2120 |
| **April** | 73 | 560 | 507 | 3888 |
| **May** | 34 | 560 | 163 | 2680 |
| **June** | 26 | 560 | 119 | 2560 |
| **July** | 24 | 560 | 106 | 2480 |
| **August** | 25 | 560 | 111 | 2500 |
| **September** | 24 | 560 | 109 | 2540 |
| **October** | 23 | 560 | 104 | 2520 |
| **November** | 47 | 560 | 304 | 3620 |
| **December** | 68 | 560 | 466 | 3840 |
| **Total** | 350 | 560 | 2001 | 3888 |

Based on the PFZs prediction maps, the results showed a wide spatial distribution of suitable fishing grounds for *Sardinella aurita* along the near coast of the North Sinai coastal zone; moreover, the potential new fishing ground areas ranged between 1120$Km^2$ in January, and 3888$Km^2$ in April. Moreover, the predicted fishing grounds are 7 times larger than that of actual fishing grounds.

Regarding the spatial resolution of PFZs, the results are in line with a recent study conducted by **Ali *et al.* (2022)** on *Sardinella aurita* fishing grounds along the Mediterranean Sea during 2018-2020. The previous authors postulated that the *Sardinella aurita* fishing grounds showed a major distribution near and along the coasts from Nile Delta to the Sinai Peninsula. Unfortunately, **Ali *et al.* (2022)** never mentioned the areas of predicted fishing grounds for *Sardinella aurita*. However, another study conducted by **Naguib *et al.* (2022)** on *Sardinellas-nei*'s fishing zones along the Red Sea in 2018 mentioned that the predicted new fishing areas were estimated to be 7 times more than the actual fishing sites area; anyhow, the latter study was conducted in a different sea with a different *Sardinella* species.

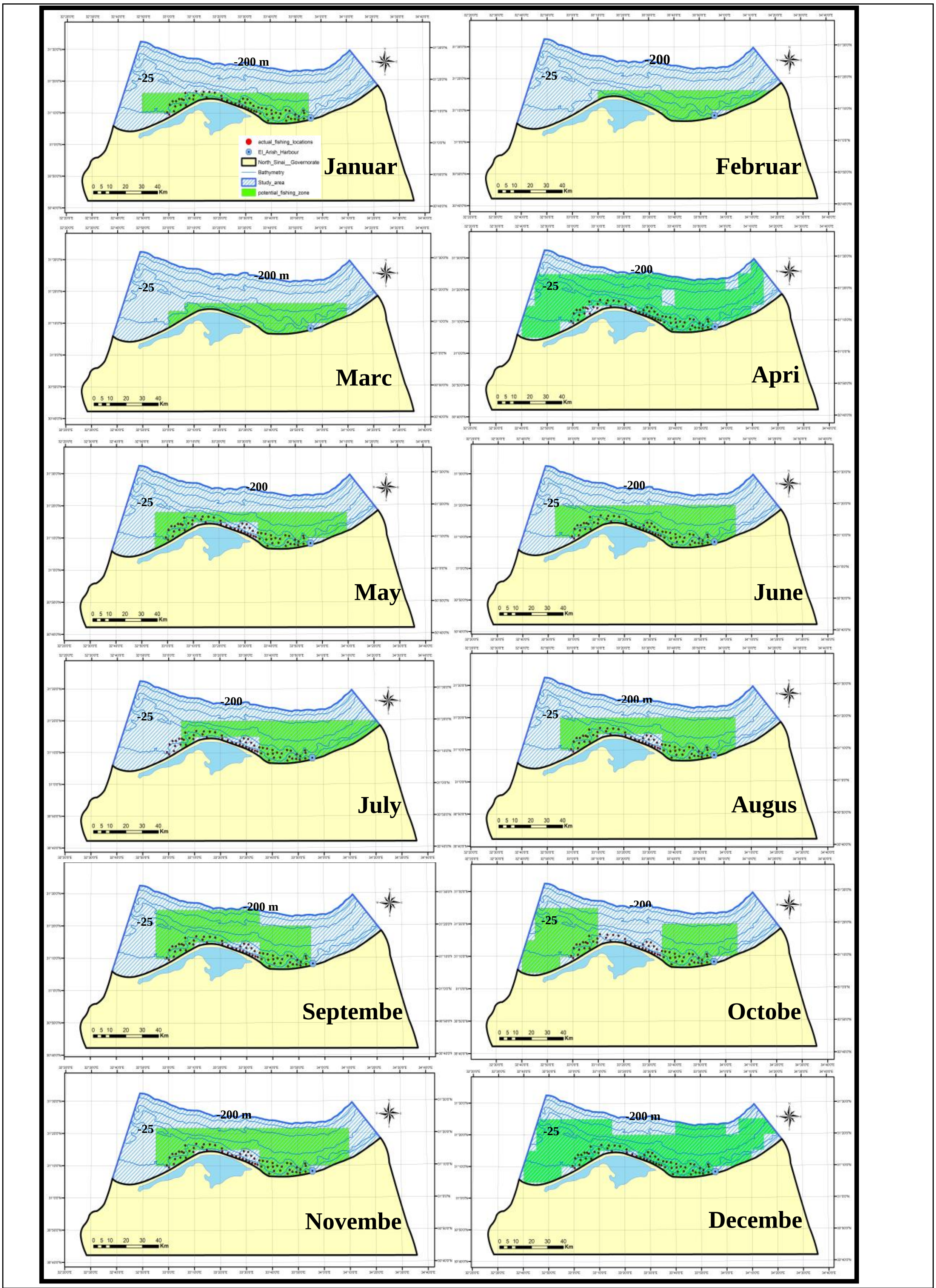


**Fig. 3.** Monthly actual and predicted map of potential fishing zones for *Sardinella aurita* over 2021 (January – December)

The PFZ prediction maps revealed that the fishing operations are carried out and concentrated in shallow waters, between 1 and 25 meters deep, for all 63 catch points that fishermen were engaged with during their fishing operations since the fishing operations mainly used the trammel nets (locally named DABBA) and the purse seines nets (locally named CHNCHOLLA). The trammel nets with a maximum net depth of 3 meters are effective in shallow water (between 1 and 3 meters deep), while the purse seines nets are effective in water with depth (between 1 and 25 meters deep).

Our results are in parallel with a large body of literature on the dominant fishing gears used in the Egyptian Mediterranean Sea, which concluded that the North Sinai fisheries are exploited by three main fishing gears, purse-seine nets, trammel nets, and longline gear **(Faltas, 1983; El-Karashily & Saleh, 1986; EL-Aiatt, 2004; Mehanna & Haggag, 2010)**.

Based on this study's maps and the field survey data outcomes, the present study revealed that the actual fishing grounds were extended from the west side of the El-Arish fishing harbor to the Bardawil Lake Strait No. I, with no commercial fishing operations in the eastern side of the El-Arish fishing harbor, which extended from the east side of El-Arish fishing harbor to the Egyptian border at Rafah; this limiting of the fishing area may be due to security reasons, such as protecting the Egyptian borders and the lives of Egyptian fishermen, as mentioned in **Desouky (2012)**.

## CONCLUSION

The traditional methods that fishermen use in fishing operations led to the mis-determination of the fishing grounds for the round *Sardinella*, the most important commercial species representing about 85% of the total catch in the North Sinai fisheries. This study achieved a suitability model for determining and predicting the optimal potential fishing grounds for *Sardinella aurita* along the North Sinai fisheries based on the multidisciplinary integration of the suitable Chl-a and SST parameters derived from Sentinel-3 satellite data, field survey outcomes, ancillary data obtained from GAFRD, and GIS model builder.

This study indicated that the optimal potential fishing grounds for *Sardinella aurita* are distributed along the North Sinai fisheries and concentrated near the inshore. The PFZs produced maps revealed that the PFZs for *Sardinella aurita* are about 7 times the actual fishing ground determined by fishermen's traditional methods. The PFZs monthly maps confirmed that the *Sardinella aurita* distribution and abundance are affected more by the SST variations since the Chl-a values were relatively suitable throughout the year. This PFZ model can be applied successfully to other fish species and marine organisms. This approach provides near-real-time robust information to help fishermen, researchers, decision-makers, and stockholders. The North Sinai fisheries are not fully exploited due to the mis-determination of optimal potential fishing grounds and undeveloped fleets and fishing gears.

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