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Retrieving climate change dependent Sea Surface Temperature (SST) in Southern Turkey by using Landsat thermal imagery

S M Kaymaz Muhling* & M Yabanli

Mugla Sitki Kocman University, Fisheries Faculty, Kotekli, Mugla – 48000, Turkey

*[E-mail: seyma.merve87@gmail.com]

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Sea Surface Temperature (SST) is one of the most significant parameters in oceanography. SST data can be used to analyse the ocean and marine environments. SST is required to study Marine Protected Areas (MPAs), identification of invasive species spreading areas, climate change, sea-level rise and pollution predictions. For more than 30 years, satellites have provided images that can assist in understanding changes in marine ecosystems. Remote data can be used as a real-time instrument for creating SST datasets. In this study, Landsat thermal data is used to retrieve sea surface temperatures. The study area of the research includes 1025 points belonging to four cross-sections of Gökova Bay in Southern Turkey. SST values were retrieved using satellite measurements for the first time in Gökova Bay. Landsat 4-5 Thematic Mapper, Landsat 7 Enhanced Thematic Mapper Plus, and Landsat 8 Operational Land Imager/Thermal Infrared Sensor imagery were analysed, covering the period from 1987 to 2017. Using geographical information systems, the satellite images were processed with algorithms, and changes in sea surface temperature were evaluated in spatiotemporal terms. As a result, a temperature anomaly of about 3 °C above average was observed in 2011 and 2015. Climate change has been shown to cause fishing losses in Gökova Bay. A relationship was identified between invasive species entering Gökova Bay and sea surface temperature data. The study method has become a useful alternative method in cases where there is a lack of *in-situ* data.

[**Keywords**: Climate change, Cross-section, Invasive species, Marine protected area, Sea surface temperature]

Introduction

Temperature has a major impact on the physical, chemical and biological features of the marine environment. Therefore, temperature data plays a significant role in a wide range of environmental resources management activities[1-3]. Sea Surface Temperature (SST) is a vital parameter in the context of biodiversity in marine environments. Furthermore, SST is a main climatological parameter[4].

For more than 30 years, infrared thermal images of the earth's surface have been collected by optical-mechanical scanner systems such as airborne satellite technologies[5,6]. These technologies now provide a chance to evaluate the brightness value of the sea from a distance[1,6]. This makes SST a valuable indicator for studying climate change.

SSTs are determined through measurements carried out at depths ranging from 1 millimetre to 20 metres. The main cause of increasing SST levels is climate warming due to excessive amounts of greenhouse gases being released into the atmosphere, which raises the water temperature at the sea surface[2,7,8,9].

The primary greenhouse gases are water vapour, carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3). In addition to carbon dioxide, some observations indicate that methane and nitrous oxide are produced in large quantities in ocean environments. However, methane and nitrous oxide are not studied as extensively as carbon dioxide. The greenhouse gases caused by climate change are absorbed by the seas and oceans. Climate change is mitigated by oceans and seas storing large quantities of carbon dioxide. The interaction between greenhouse gases and ocean waters influences the rate at which climate change impacts occur. Carbon absorption reduces the acidity of seawater, making it harder for corals and shellfish to build their skeletons. The Great Barrier Reef and western coral reefs, as well as the Caribbean and South China Seas, are also suffering from mass bleaching[10-16].

SSTs increase due to the oceans absorbing excessive heat, and melting glaciers, causing sea levels to rise. This causes coastal areas to flood, erode, and destroy habitats. In the studies carried out, north-west Europe, India/Bay of Bengal, south-east and East Asia are among the regions with significant increases in flooding. In addition to the Atlantic and Pacific coasts of North America, the North Sea coast of Europe and China is also at risk of flooding. Furthermore, rising sea levels will cause powerful storms to develop in the tropics, causing loss of life and property. The biodiversity and productivity of the ocean can be drastically altered as a result of these impacts[17]. The global SSTs are expected to increase between 0.4 – 1.1 °C by 2025, according to the Intergovernmental Panel on Climate Change[18,19].

The main reason for evaluating SST changes is that species are adapted to their natural range of temperatures, which influences migration, breeding and blooms periods, coral reef bleaching, nutrient cycles and sea level changes. Thus, by evaluating the frequency of SST anomalies we can take precautions against the potential impacts of SST changes on the marine ecosystem[20,21]. Increasing surface water temperatures also promote the spread of invasive species in Gökova Bay. There was an increase in the number of invasive species that came through the Suez Canal and settled in Gökova Bay. The distribution of invasive species is likely to be affected by climate change due to seawater temperature rise. The majority of invasive species live in tropical waters (22 – 28 °C), are tolerant to high salinity, and have adaptable habitats[22-24].

In Gökova Bay, 86 alien species were detected from 25 different taxa. Among these, 37 were invasive species that entered Gökova Bay by way of the Suez Canal. These invasive species were from the taxa, Tracheophyta, Scyphozoa, Annelida, Stomatopoda, Decapoda, Bivalvia, Echinodermata and Actinopterygii[25]. The SST measurements show us the number of temperature anomalies that exceed the normal range of changes for a specific location. The frequency of such anomalies indicates how severely a location is affected by extremely high temperatures[18].

The present study aims to use the SST retrieving technique with the hotspot area. It uses Landsat 4-5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 Operational Land Imager (OLI)/Thermal Infrared Sensor (TIRS) satellite imagery for estimating and mapping SST in the period from 1987 to 2017 in Gökova Bay. The results were evaluated in terms of climate change impacts on the bay's marine ecosystem. A relationship has also been established between invasive fish species that enter the Gökova Bay *via* the Suez Canal and the sea surface water temperature. The study method has become a useful alternative in cases where there is a lack of *in-situ* data.

Material and Methods

Study area and sampling site

The study area is the Bay of Gökova, which is located in the South Aegean Sea. It extends in an East-Westerly direction between the Bodrum Peninsula in the North and the Datca Peninsula in the south (Fig. 1). There are two deep basins in the bay, the eastern deep basin and the western deep basin. The depth of the shelf reaches 104 m. The depth is approximately 540 m(ref. 26).

Gökova Bay is influenced by the waters of the Levantine basin and represents the water features of the South Aegean Sea. The Asia minor current which

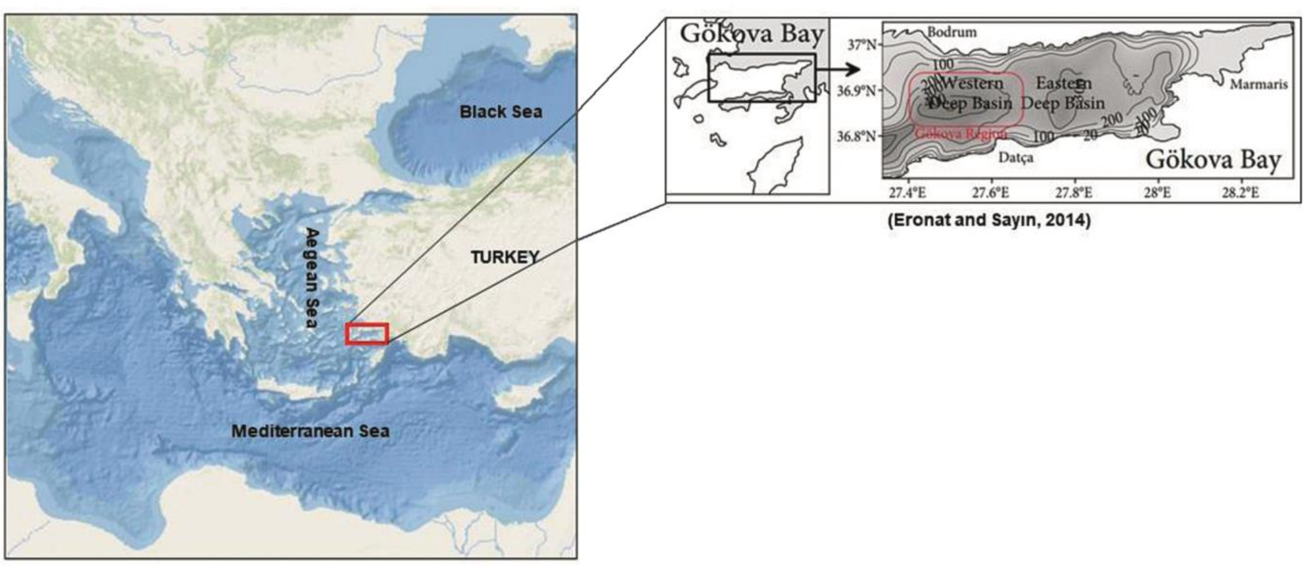

Fig. 1 — Map of the study area, Bay of Goköva

flows between the Turkish mainland and the island of Rhodes brings warm Levantine surface water and salty Levantine intermediate water into the Bay of Gökova[26,27]. Reaching the bay through its south-western entrance, the Levantine waters extend to the middle of the bay in every season[26]. The bay, which is one of Turkey's eight marine protected areas (MPAs), was declared a "Special Environmental Protection Area (SEPA)" in 1989[refs. 28,29]. Situated at the intersection between the Mediterranean and the Aegean Sea, the bay is one of the largest and most abundant in Turkey. It is essential in terms of biodiversity because species that originate in the Indian Ocean pass through the Suez Canal into the Turkish seas[28,30-32].

Gökova Bay was studied by creating four different sections. The inner bay is represented by the T1 section, the eastern basin of the bay is referred to as the T2 section, the western basin of the bay is represented by T3 and the bay line from east to west is represented in the T4 section (Fig. 2).

Landsat thermal data

For the study, 36 Landsat thermal images were used. These images were taken between 1987 and 2017, with several years not represented (1988 – 1999, 2003 – 2008 and 2012) due to an absence of Landsat observations. The images represent the summer season (June, July and August), because passive sensor satellites like Landsat cannot obtain accurate data in the winter season due to clouds and fog. The Level-1 (L1) data (Table 1) were extracted from the United States Geological Survey[33].

SST calculation and mapping

The European Datum 1950 UTM Zone 35N projection was employed in this study. First, using ArcGIS 10.4 (Map Algebra toolset), the data were converted from Digital Numbers (DNs) (1) into radiance values using the bias and gain values from the header files. Then, the radiance values were converted into black body temperature. Geometric defects were eliminated in the satellite images, starting with systematic errors and followed by non-systematic errors, including scan skew, earth rotation, panoramic distortion, scanner mirror velocity, platform speed, and perspective projection.

***Gain and Bias method*[34]**

$$L\lambda = \text{Gain}\,(\text{QCAL}) + \text{Bias} \qquad \dots (1)$$

Where, Lλ: The cell value as radiance, QCAL: The cell value digital number, Gain: The gain value for a

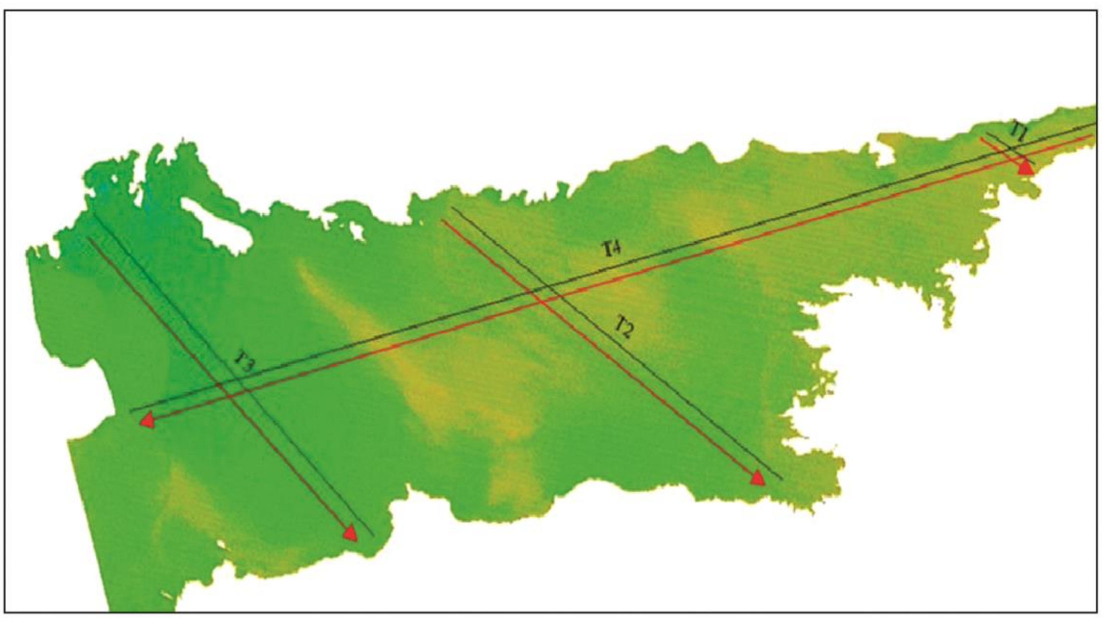

Fig. 2 — The four sections of the sampling site

Table 1 — Landsat images features (29)

	Product Type	Pixel size (collected)	Pixel size (resampled)	Thermal band
Landsat 4-5 TM	L1	120-meters	30-meters	Band 6
Landsat 7 ETM+	L1	60-meters	30-meters	Band 6
Landsat 8 OLI/TIRS	L1	100-meters	30-meters	Band 10/ Band11

specific band watt / (m^2 * ster * μm), Bias: The bias value for specific band watt / (m^2 * ster * μm).

In the second step, the radiance values were converted to Top of Atmosphere (ToA) radiance values in Kelvin (2). While making these calculations, K1 and K2 constants of all images were used (Table 2).

***Conversion of spectral radiance to temperature in Kelvin*[34]**

$$T = K2 / (\ln (K1 / L\lambda) + 1) \quad \ldots (2)$$

Where, T: Degrees Kelvin, K2: Calibration constant 2, K1: Calibration constant 1, Lλ: Spectral brightness watt / (square meter * ster * μm).

In the last step, the converted temperature values were converted from Kelvin to Celsius (3).

***Conversion of Kelvin to Celsius*[34]**

$$T\,(\text{Celsius}) = T\,(\text{Kelvin}) - 273 \quad \ldots (3)$$

After the calculation, four sections were drawn across the sampling site using the cross-section tool (perpendicular profiles along the path) on Global Mapper 10.4. Cross-section is a significant tool for building 2D and 3D models. In this study, cross-sections display the vertical dimensions of sea surface temperatures on satellite images.

The process of the cross-section is based on the output of intermediate cross-sections and the transformation of the elevations interpolated in a cross-section to the 2D model. In each selected cross-section the elevation is determined by the value of the transversal coordinate at the point projected previously[35]. In this study, the number of measurement points per cross-section profile is 1025 in raster format. The cross-section tool allows saving the path profile as a text file, thus converting the 1025 points into an xyz file. The values in the xyz text file were then statistically analysed with the STAT 10 program.

Results

The temperature values were displayed as maps of SST distribution (Figs. S1 – S3). The maps show the spatio-temporal variation of SST in Gökova Bay in June, July and August, respectively. The SST maps show that between 1987 and 2017, the SST in Gökova Bay ranged between 20.15 and 26.25 °C in June (Fig. S1), between 20.4 and 27.1 °C in July (Fig. S2) and between 21.4 and 26 °C in August (Fig. S3). The maps also show that these monthly SST values fluctuated considerably from year to year, with major ups and downs occurring irregularly.

Table 2 — K1 and K2 constants of Landsat images

Constants	K1 - w/(m^2* ster * μm)	K2 Kelvin
Landsat 4 TM	671.62	1284.30
Landsat 5 TM	607.76	1260.56
Landsat 7 ETM+	666.09	1282.71
Landsat 8 OLI/TIRS	774.89	1321.08

The approach that was used for retrieving SST values was based on satellite measurements. For each section, pixel values were extracted. Statistical analysis was performed for the remotely sensed SST values, and graphs for each cross-section were developed using satellite-derived data. The highest temperature anomaly found for cross-section T1 was 2.85 °C above average in July 2017 (Fig. 3a). For cross-section T2, the highest anomaly was 3.5 °C in August 2015 (Fig. 3b), while for cross-section T3, the two peaks were 3 °C in August 2011 and 3.2 °C in August 2015 (Fig. 3c). The highest anomaly for cross-section T4 was 3.5 °C above average in August 2015 (Fig. 3d). In August, the SST generally fluctuated more (between 3 – 3.5 °C) than in June and July.

Temperature is one of the major parameters for all oceanographic and physical aspects of climate change in the marine environment at regional and local scales. Besides, the sea plays a main role in the process of heat absorption. Gökova Bay is a significant example of a place where SST changes have been observed with satellite-driven data at the local scale. According to IPCC, rising global SSTs are estimated at 0.4 to 1.1 °C in 2025. According to Lionello (2012)[36], SSTs will rise by 2.5 °C in 2100. The results of this study, which allow us to examine global warming effects on a local scale, show that the Gökova SST change is higher than these estimations.

Figure 3 (a – d) show SST anomalies observed in spatial patterns for each summer month. The highest SST anomalies were observed at cross-sections T2 (Middle) and T3 (Outer). The spatial maps of the satellite-derived SST linear trend over the 1987 – 2017 period show stable, increasing surface temperatures. A more comprehensive examination of the spatial maps shows that SST distributions do not display temporal behaviour in the bay. From 1987 to 2017, the satellite-derived data shows that the SST increase is more significant towards the northern coast of the bay. A relatively low SST increase was observed in the Outer Bay area northwest of the Aegean Sea. According to the average SST values of Gökova Bay between 1987 and 2017, temperatures increase linearly in June, July and August (Fig. 4).

Furthermore, the increase in temperatures in the Bay waters has led to an influx of invasive species[25]

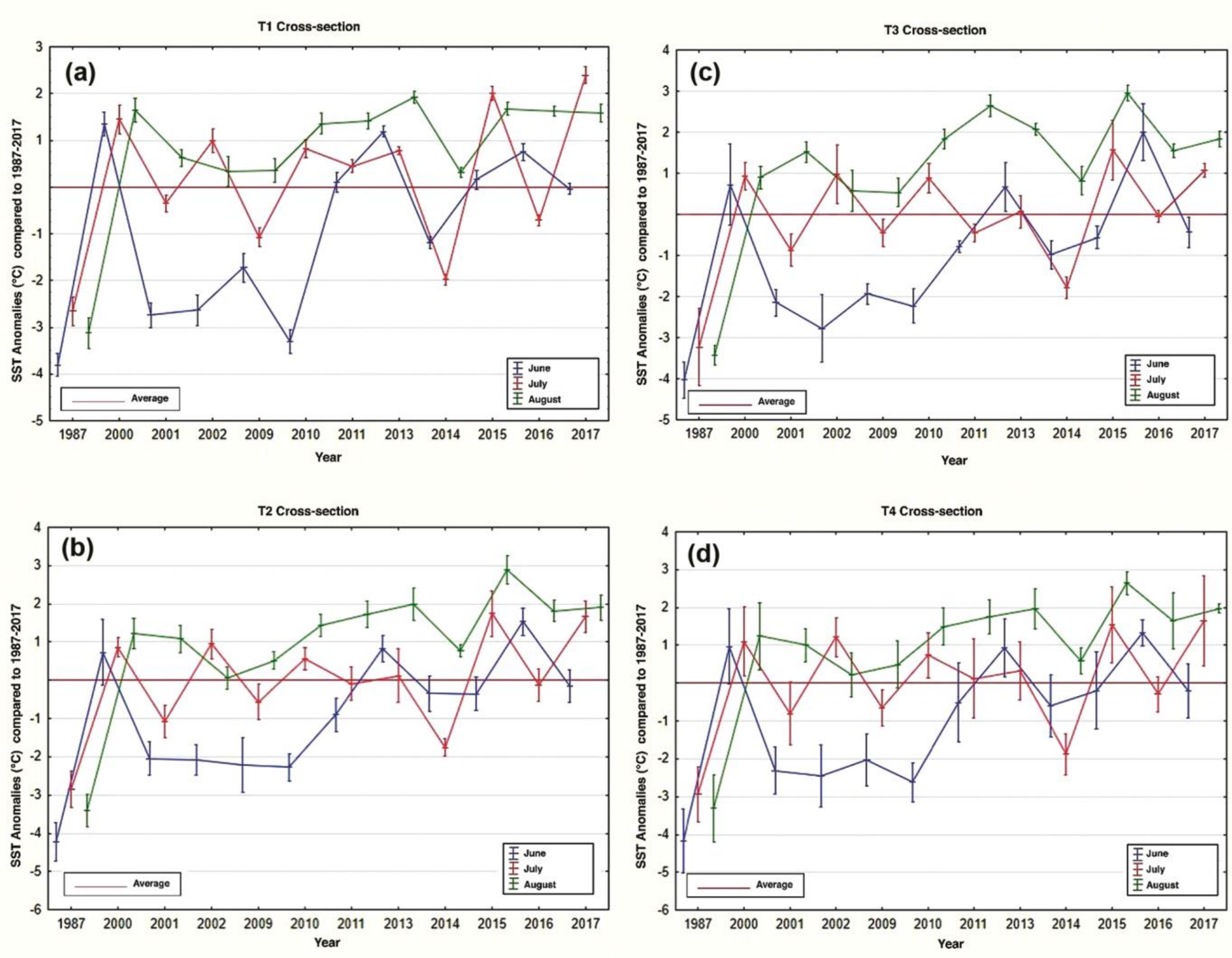

Fig. 3 — SST anomalies: a) T1 Cross-section, b) T2 Cross-section, c) T3 Cross-section, and d) T4 Cross-section

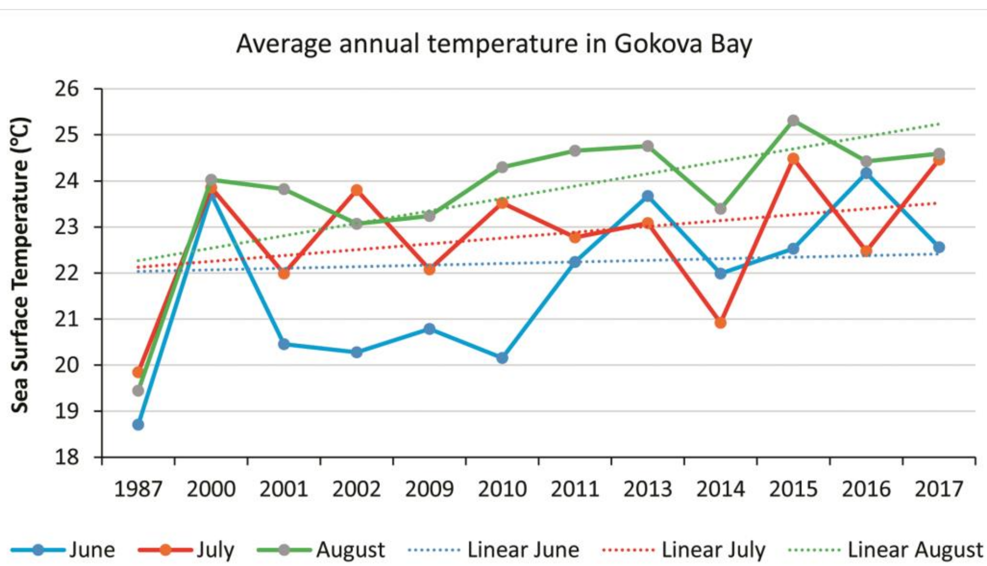

Fig. 4 — Average annual temperature in Gökova Bay

which are *Alepes djedaba* (Forsskål, 1775), *Atherinomorus forskalii* (Rüppell, 1838), *Champsodon nudivittis* (Ogilby, 1895), *Equulites klunzingeri* (Steindachner, 1898), *Etrumeus golanii* (DiBatistta, Randall and Bowen, 2012), *Fistularia commersonii* (Rüppell, 1835), *Fistularia petimba* (Lacepède, 1803), *Lagocephalus guentheri* (Richardson, 1844), *Lagocephalus sceleratus* (Gmelin, 1789), *Lagocephalus suezensis* (Clark & Gohar, 1953), *Nemipterus randalli* (Russell, 1986), *Parupeneus forskalli* (Fourmanoir & Guézé, 1976), *Pterois miles* (Bennett, 1828), *Saurida lessepsianus* (Russell, Golani and Tikochinski, 2015), *Siganus luridus* (Rüppell, 1829), *Siganus rivulatus* (Forsskål, 1775), *Sphyraena chrysotaenia* (Klunzinger, 1884), *Torquigener flavimaculosus* (Hardy & Randall, 1983), *Upeneus moluccensis* (Bleeker, 1855), and *Upeneus pori* (Ben-Tuvia & Golani, 1989).

Conclusion

The findings in the SST maps (Figs. 4, S1, S2) show a long-term surface warming of the bay. In recent years, a tropical flow has been detected from Gibraltar Strait to the Mediterranean Sea due to climate change[32,37]. The results of this study show that the water masses of the bay have become tropicalized and that the new Mediterranean has formed in the bay. This change remarkably increases the number of invasive species entering through the Suez Canal into the Gökova Bay[30,37]. It is seen that *Etrumeus golanii* (DiBatistta, Randall & Bowen, 2012), *Fistularia petimba* (Lacepède, 1803), *Lagocephalus guentheri* (Richardson, 1844), *Nemipterus randalli* (Russell, 1986), *Parupeneus forsskali* (Fourmanoir & Guézé, 1976), *Pterois miles* (Bennett, 1828), *Saurida lessepsianus* (Russell, Golani & Tikochinski, 2015), and *Torquigener flavimaculosus* (Hardy & Randall, 1983) were invasive species and were not in the list in the study carried out by Cinar *et al.*[37]. The study carried out by Bilecenoglu & Cinar[25] found that these species had entered Gökova Bay. The graphs (Figs. 3, 4) indicate that temperatures have increased linearly since 2015. It was concluded from these data that the entry of eight newly discovered species into Gökova Bay is directly proportional to the increase in sea surface water temperature. The annual average SST values shown in Figure 4 indicate that invasive species have begun to enter Gökova Bay since 1987. Furthermore, SST values (Fig. 4) indicate that invasive species in Gökova Bay have formed a permanent habitat for feeding, reproducing and growing since 2015.

According to Figure 4, when Cinar *et al.*[37] reported the number of invasive species in 2010 and Bilecenoglu & Cinar[25] reported the number in 2021, it is the increase in SST that is responsible for the increase in invasive species.

The economy of the Gökova region is based on marine tourism, agriculture, and fishing. Due to the bay's protective status, fishing has only developed on a small scale[29,38].

Also, the study carried out by Unal *et al.*[39] between 2013 and 2014 revealed the damages inflicted on fisheries by the Silver-cheeked toadfish (*Lagocephalus sceleratus*), which is one of the rapidly increasing invasive species (including Eastern Mediterranean and Gökova MPA). According to the data obtained by the study, local fishermen suffer an economic loss of approximately 6.033.577 TL (≈ € 2 051 416) per year[38] through damages to their fishing gear and decreases in their catch. There is no predator for this species in the Mediterranean at present. Furthermore, with the increase in the temperature of the Bay waters, invasive species such as Randall's threadfin bream (*Nemipterus randalli*), Brushtooth lizardfish (*Saurida undosquamis*), Marbled spinefoot (*Siganus rivulatus*), and Goldband goatfish (*Upeneus moluccensis*) are entering the Bay. These species are not as harmful as the Silver-cheeked toadfish, and they are caught in amounts of about 15 – 25 kg every day and have started to take their place among commercial species in the last few years in Gökova Bay[38,39]. Even though many invasive species were caught by fishermen, they were thrown back into the sea due to a lack of knowledge about them. In some countries, however, different solutions are being developed to combat invasive species.

Consumption of invasive species has been encouraged in Denmark, America, Greece, and Turkey to prevent this invasion. Restaurants in these countries have begun introducing lionfish and bivalve to their menus[40-42]. In Greece, a citizen science program called iSea ("Is it Alien to you? Share it!") encourages local people to share invasive species[43]. RELIONMED-LIFE is an EU-funded project in Cyprus designed to prevent the invasion of lionfish[44]. Pufferfish are one of several invasive species in Turkey, and fishermen are encouraged to catch it and are compensated by the Ministry of Agriculture and Forestry according to the species and amount[45,46]. As well, the Marine Invasive Alien Species Project is implemented by the Turkish General Directorate of Nature Conservation and National Parks in collaboration with UNDP and financed by the Global Environment Facility (GEF). This project is aimed at enhancing the resilience of Turkish marine and coastal ecosystems by preventing, detecting, controlling, and managing invasive alien species[47]. Israel has coastlines on both the Mediterranean Sea and the Red Sea, and the lionfish is native to the Red Sea. Under Israeli regulations, the lionfish is a protected species. These regulations impede the implementation of management interventions in the Mediterranean[48,49]. But invasive species are still one of the most significant threats to the resources of Gökova MPA and thus are considered the most important problem among local traditional fishermen.

According to the results of this study, rising temperatures would damage the livelihood of small-scale fishermen in the bay because of an increasing spread of invasive species, which compete with native species in the bay in ecological and economical terms.

MPA generally are used to preserve species, habitats, and ecosystems, and they are essential for conserving ecological functions[50-52]. But the species that inhabit them are shifting due to climate change, with invasive species replacing native species in the bay. As a result, it is no longer clear whether the MPA protects native or invasive species. Due to the increase in SST caused by climate change, the area should be re-examined, and if necessary, the conditions of the protected area should be updated. Also, the SST in the MPA should be examined and monitored continuously in order to detect changes in the bay.

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Supplementary Data

Supplementary data associated with this article is available in the electronic form at http://nopr.niscpr.res.in/jinfo/ijms/IJMS_51(07)597-605_SupplData.pdf

Conflict of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

Ethical Statement

This is to certify that the reported work in the paper entitled "Retrieving climate change dependent Sea Surface Temperature (SST) in Southern Turkey by using Landsat thermal imagery" submitted for publication is an original one and has not been submitted for publication elsewhere. We further certify that proper citations to the previously reported work have been given and no data/table/figure has been quoted verbatim from other publications without giving due acknowledgement and without the permission of the author(s). The consent of all the authors of this paper has been obtained for submitting the paper to the 'Indian Journal of Geo-Marine Sciences'.

Author Contributions

Conceptualization, Methodology, Writing - original draft preparation and Writing - reviewing and editing: SMKM & MY; Analysis: SMKM.

References

1 Lillesand T M & Kiefer R W, *Remote Sensing and Image Interpretation*, (John Wiley & Sons, New York), 1987, pp. 736.

2 EPA, *Climate change indicators: sea surface temperature*, (United States Environmental Protection Agency), 2016. https://www.epa.gov/climate-indicators/climate-change-indicators-sea-surface-temperature (Accessed on: 08/ 2019).

3 National Oceanic and Atmospheric Administration (NOAA), NOAA Merged Land Ocean Global Surface Temperature Analysis (NOAAGlobalTemp): Global gridded 5° × 5° data. National Centres for Environmental Information, 2016. Accessed on 12/2016. www.ncdc.noaa.gov/data-access/marineocean-data/noaa-global-surfacetemperature-noaaglobaltemp

4 Wloczyk C, Richter R, Borg E & Neubert W, Sea and lake surface temperature retrieval from Landsat thermal data in Northern Germany, *Int J Remote Sens*, 27 (12) (2006) 2489-2502. http://dx.doi.org/10.1080/01431160500300206

5 Bartolucci L A, Chang M, Anuta P E & Graves M R, Aton Landsat TM thermal Infrared data, *IEEE Trans Geosci Remote Sens*, 8 (1988) 1509-1522.

6 Tarigan S & Wouthuyzen S, Mapping and Monitoring the Sea Surface Temperature in Weda Bay Using Terra and Aqua- Modis Satellites, *J Remote Sens GIS*, 6 (2017) p. 4. DOI: 10.4172/2469-4134.1000217

7 Tseng C T, Sun C L, Yeh S Z, Chen S C, Su W C, *et al.*, Influence of climate-driven sea surface temperature increase on potential habitats of the Pacific saury (*Cololabis saira*), *ICES J Mar Sci*, 68 (6) (2011) 1105–1113. DOI:10.1093/icesjms/fsr070

8 Hoegh-Guldberg O & Bruno J F, The impact of climate change on the world's marine ecosystems, *Science*, 328 (5985) (2010) 1523-1528. DOI: 10.1126/science.1189930

9 National Climate Assessment (NAC), Report Findings: Oceans, 2014. http://nca2014.globalchange.gov/highlights/report-findings/oceans (Accessed on: 08/ 2016).

10 McWilliams J P, Côté I M, Gill J A, Sutherland W J & Watkinson A R, Accelerating impacts of temperature-induced coral bleaching in the Caribbean, *Ecology*, 86 (86) (2005) 2055-2060. https://doi.org/10.1890/04-1657

11 Maynard J A, Turner P J, Anthony K R N, Baird A H, Berkelmans R, *et al.*, ReefTemp: an interactive monitoring system for coral bleaching using high-resolution SST and improved stress predictors, *Geophys Res Lett*, 35 (5) (2008) p. L05603. https://doi.org/10.1029/2007GL032175

12 Stuart-Smith R D, Brown C J, Ceccarelli D M & Edgar G J, Ecosystem restructuring along the Great Barrier Reef following mass coral bleaching, *Nature*, 560 (2018) 92–96. https://doi.org/10.1038/s41586-018-0359-9

13 Hennige S J, Wolfram U, Wickes L, Murray F, Roberts J M, *et al*., Crumbling reefs and coral habitat loss in a future ocean: evidence of 'coralporosis' as an indicator of habitat integrity, *Front Mar Sci*, 7 (2020) p. 668. https://doi.org/10.3389/ fmars.2020.00668

14 Lyu Y, Zhou Z, Zhang Y, Chen Z, Deng W, *et al*., The mass coral bleaching event of inshore corals from South China Sea witnessed in 2020: insight into the causes, process and consequence, *Coral Reefs*, 2022. https://doi.org/10.1007/s00338-022-02284-1

15 Collins M, Sutherland M, Bauwer L, Cheong S M, Frölicher T, *et al*., Extremes, Abrupt Changes and Managing Risk, In: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*, edited by H-O Pörtner, D C Roberts, V Masson-Delmotte, P Zhai, M Tignor, *et al*., (Cambridge University Press, Cambridge, UK), 2019, pp. 589-655. https://www.ipcc.ch/site/assets/uploads/sites/3/2022/03/08_SROCC_Ch06_FINAL.pdf

16 Turley C, Racault M F, Roberts J M, Scott B E, Sharples J, *et al.*, Why the Ocean Matters in Climate Negotiations, *COP26 Universities Network Briefing, 2021*. https://www.iass-potsdam.de/sites/default/files/2021-06/COP26%20Ocean%20Briefing.pdf

17 Kirezci E, Young I R, Ranasinghe R, Muis S, Nicholls R J, *et al.*, Projections of global-scale extreme sea levels and resulting episodic coastal flooding over the 21st Century, *Sci Rep*, 10 (2020) p. 11629. https://doi.org/10.1038/s41598-020-67736-6

18 Intergovernmental Panel on Climate Change (IPCC), IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation, (IPCC 2011). https://www.ipcc.ch/site/assets/uploads/2018/03/SRREN_Full_Report-1.pdf (Accessed on: 11/2019).

19 International Panel on Climate Change (IPCC), Fourth Assessment Report: Climate Change 2007. (IPCC 2007). http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml (Accessed on: 11/2019).

20 Ostrander G K, Armstrong K M, Knobbe E T, Gerace D & Scully E P, Rapid transition in the structure of a coral reef community: The effects of coral bleaching and physical disturbance, *Proc Natl Acad Sci USA*, 97 (10) (2010) 5297–5302. DOI: 10.1073/pnas.090104897

21 Deser C, Phillips A & Alexander M, Twentieth century tropical sea surface temperature trends revisited, *Geophys Res Lett*, 37 (2010) 1–6. doi:10.1029/2010GL043321

22 Occhipinti-Ambrogi A & Savini D, Biological invasions as a component of global change in stressed marine ecosystems, *Mar Pollut Bull*, 46 (2003) 542–551. DOI: 10.1016/S0025-326X(02)00363-6

23 Colautti R I & MacIssac H J, A neutral terminology to define "invasive species", *Diversity and Distributions*, 10 (2004) 135–141. https://doi.org/10.1111/j.1366-9516.2004.00061.x

24 Öztürk B, Non-indigenous species in the Mediterranean and the Black Sea, *Stud Review*, No. 87 (General Fisheries Commission for the Mediterranean), (Rome, FAO), 2021, pp. 106. https://doi.org/10.4060/cb5949en

25 Bilecenoğlu M & Çınar M E, Alien Species Threat across Marine Protected Areas of Turkey—An Updated Inventory, *J Mar Sci Eng*, 9 (2021) p. 1077. https://doi.org/10.3390/jmse9101077

26 Eronat C & Sayın E, Temporal evolution of the water characteristics in the bays along the eastern coast of the Aegean Sea: Saros, İzmir, and Gökova bays, *Turkish J Earth Sci*, 24 (2014) 53-66. DOI:10.3906/yer-1307-4

27 Millot C & Taupier-Letage I, Circulation in the Mediterranean Sea, In: *The Mediterranean Sea. Handbook of Environmental Chemistry*, Vol 5, Part K, edited by A Saliot, (Springer, Berlin), 2005, pp. 29-66.

28 Cihangir B, Benli H A, Cirik Ş, Ünlüoğlu A & Sayın E, Bioecological properties of Gökova Bay (in Turkish with English abstract), *Proceedings of Symposium on Bodrum Peninsula Enviromental Problems, Bodrum*, 1998, pp. 647-662,

29 Ünal V & Kızılkaya Z, A Long and Participatory Process towards Successful Fishery Management of Gökova Bay, Turkey, In: *From Catastrophe to Recovery: Stories of Fishery Management Success*, edited by C C Krueger, W W Taylor & S J Youn, (American Fisheries Society, USA), 2019, pp. 509-532.

30 Cochrane K, De Young C, Soto D & Bahri T, Climate change implications for fisheries and aquaculture: overview of current scientific knowledge. FAO (Food and Agriculture Organization of the United Nations) Fisheries and Aquaculture Technical Paper 530, 2009. http://www.fao.org/fileadmin/user_upload/newsroom/docs/FTP530.pdf (Accessed on: 01/ 2020).

31 Kıraç C O, Orhun C, Toprak A, Veryeri N O, Orsi U G, *et al.*, Integrated Coastal and Marine Zone Management of Gökova Special Protection Area (in Turkish), *National Conference of Turkish Coasts*, 2010, pp. 1-10.

32 Skrilis N, Sofianos S, Gkanasos A, Mantziafou A, Vervatis V, *et al.*, Decadal scale variability of sea surface temperature in the Mediterranean Sea in relation to atmospheric variability, *Ocean Dyn*, 62 (2011) 13–30. DOI 10.1007/s10236-011-0493-5

33 United States Geological Survey (USGS), Landsat—Earth Observation Satellites, 2015. https://pubs.usgs.gov/fs/2015/3081/fs20153081.pdf (Accessed on: 05/ 2017).

34 Irons J, Landsat science data user's handbook, in, Report 430-15-01-003-0. National Aeronautics and Space Administration. NASA, 2012. https://landsat.gsfc.nasa.gov/wp-content/uploads/2016/08/Landsat7_Handbook.pdf. Accessed on 23 November 2016

35 Dysarz T, Development of RiverBox—An ArcGIS toolbox for river bathymetry reconstruction, *Water*, 10 (9) (2018) 1266. DOI:10.3390/w10091266
36 Lionello P, *The climate of the Mediterranean region from the past to the future*, (Elsevier-USA), 2012, pp. 592.
37 Çınar M E, Bilecenoğlu M, Öztürk B, Katağan T, Yokeş M B, *et al.*, An updated review of alien species on the coasts of Turkey, *Mediterr Mar Sci*, 12 (2) (2011) 257–315. DOI: https://doi.org/10.12681/mms.34
38 Ünal V, Yıldırım Z D & Tıraşın E M, Implementation of the ecosystem approach to fisheries for the small-scale fisheries in Gökova Bay, Turkey: baseline report. FAO Fisheries and Aquaculture Technical Paper No. 646, (FAO, Rome), 2019, pp. 68.
39 Ünal V, Göncüoğlu H, Durgun D, Tosunoglu Z, Deval C, *et al*., Silver-cheeked toadfish, *Lagocephalus sceleratus* (actinopterygii: tetraodontiformes: tetraodontidae), causes substantial economic losses in the Turkish Mediterranean coast: a call for decision makers, *Acta Ichthyol Piscat*, 45 (3) (2015) 231–237. DOI:10.3750/AIP2015.45.3.02
40 Manacıoglu T & Manacıoglu S, Lionfish preparation for cooking in Turkey, In: *Lionfish Invasion and Its Management in the Mediterranean Sea*, edited by M F Hüseyinoğlu & B Öztürk, (Turkish Marine Research Foundation (TUDAV) Publication no: 49, Istanbul, Turkey), 2018, pp. 110-117.
41 Rac/Spa MPA-based entrepreneur turns invasive fish species into a local delicacy, 2019. http://rac-spa.org/node/2019
42 Berent L, Flückiger P, Gritti F, Kreimeier N, Kunert K, *et al.*, 24 Stunden rund um die Ostsee, *Stern*, 31 (2022) p. 110 (in German).
43 Giovos I, Batjakas I, Doumpas N, Kampouris T E, Poursanidis D, *et al*., The current status of lionfish invasion in Greece and future steps towards control and mitigation, In: *Lionfish Invasion and Its Management in the Mediterranean Sea*, edited by M F Hüseyinoğlu & B Öztürk, (Turkish Marine Research Foundation (TUDAV) Publication no: 49, Istanbul, Turkey), 2018, pp. 17-33.
44 Bilecenoğlu M, Controlling the lionfish invasion in the eastern Mediterranean Sea, In: *Lionfish Invasion and Its Management in the Mediterranean Sea*, edited by M F Hüseyinoğlu & B Öztürk, (Turkish Marine Research Foundation (TUDAV) Publication no: 49, Istanbul, Turkey), 2018, pp. 1-9.
45 Official Gazette of the Republic of Turkey, 2021. https://www.resmigazete.gov.tr/eskiler/2021/06/20210627-8.htm
46 Official Gazette of the Republic of Turkey, 2022. https://www.resmigazete.gov.tr/eskiler/2022/08/20220805.pdf
47 MARIAS, 2022. https://mariasturk.org/marias/
48 The Israeli Ministry of Environmental Protection, *Declaration of national parks, nature reserves, national sites and protected natural products*, 2005, pp. 1–9.
49 Stern N & Rothman S B, Divide and conserve the simultaneously protected and invasive species, *Aquat Conserv*, (2018) 1-2. Doi: 10.1002/aqc.2950
50 Johnston A, Ausden M, Dodd A M, Bradbury R B, Chamberlain D E, *et al*., Observed and predicted effects of climate change on species abundance in protected areas, *Nat Clim Change*, 3 (12) (2013) 1055–1061. DOI:10.1038/nclimate2035
51 Otero M, Garrabou J & Vargas M, *Mediterranean Marine Protected Areas and climate change: A guide to regional monitoring and adaptation opportunities*, (IUCN, Malaga, Spain), 2013. https://portals.iucn.org/library/sites/library/files/documents/2013-019.pdf (Accessed on: 07/2019).
52 Gross J E, Woodley S, Welling L A, Watson J E M (eds.), Adapting to Climate Change: Guidance for protected area managers and planners, Best Practice Protected Area Guidelines Series No. 24, (Gland, Switzerland), 2016, xviii + 129 pp.