



Monitoring *Tilapia* (*Tilapia* spp.) Population in Köyceğiz Lake of Turkey by Thermal Bands of LANDSAT-5 TM and LANDSAT-7 ETM+ Satellite Images

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Abstract: Invasive *Tilapia* fish (*Tilapia* spp.) numbers in Köyceğiz Lake of Turkey were monitored in 1993, 1999 and 2012 by utilizing the thermal bands of LANDSAT-5 TM and LANDSAT-7 ETM+ images. Geo-referenced archival field data, collected from 4 stations on Köyceğiz Lake between January and December of 1993, was used to develop a model. Detecting significant positive correlation (0.88) between fish numbers and water temperature, polynomial regression analysis with the second order was conducted to develop a model. Obtained model was applied to the thermal bands of a LANDSAT-5 TM image taken in 1995, and two LANDSAT-7 ETM+ images taken in 1999 and 2012. Consequently, the fish numbers and Catch Per Unit Effort (CPUE) in those three years were mapped and monitored. Overall results showed that *Tilapia* fish populations tend to be increase with increasing water temperature in Köyceğiz Lake.

Keywords: Geographic information systems, remote sensing, *Tilapia* fish, spatial analysis, water temperature.

Köyceğiz Gölündeki *Tilapia* Populasyonunun Landsat-5 TM ve Landsat-7 ETM+ Uydu Görüntülerinin Termal Bandları Kullanılarak İzlenmesi

Öz: Köyceğiz Gölü'ndeki istilacı *Tilapia* balıkları (*Tilapia* spp.) sayıları, 1993, 1999 ve 2012 yıllarında LANDSAT-5 TM ve LANDSAT-7 ETM + görüntülerinin termal bantları kullanılarak izlenmiştir. Ocak-Aralık 1993 tarihleri arasında Köyceğiz Gölü'nde 4 istasyondan toplanan jeo-referanslı arşiv sahası verileri model geliştirmeye alınmıştır. Balık sayıları ve sıcaklık arasında anlamlı pozitif korelasyon (0.88) tespit edilmiş, ikinci derece ile polinom regresyon analizi ile model geliştirilmiştir. Elde edilen model, 1995 yılında alınan LANDSAT-5 TM görüntüsünün termal bantlarına, 1999 ve 2012 yıllarında alınan iki LANDSAT-7 ETM + görüntüsüne uygulanmıştır. Sonuç olarak, bu üç yıldaki balık sayıları ve Catch Per Unit Effort (CPUE) haritalandırılmış ve izlenmiştir. Sonuçlar, Köyceğiz Gölü'nde su sıcaklığı arttıkça *Tilapia* balık popülasyonlarının artma eğiliminde olduğunu göstermiştir.

Anahtar Kelimeler: Coğrafi Bilgi Sistemleri, uzaktan algılama, *Tilapia* balıkları, mekansal analiz, su sıcaklığı.

1. Introduction

Invasive species are most commonly defined as a non-native species that dominates the encountered ecosystem and impairs its function and structure. On a global scale, invasive species belong to the main reasons of biodiversity loss (Ficetola et al., 2007) and cause substantial economic damage. Members of the family Cichlidae are generally referred to as *Tilapias*

(*Tilapia* spp.). *Tilapias* are tolerant of wide fluctuations in salinity (Stickney, 1986), dissolved oxygen, and temperature (Febry and Lutz, 1987; Avella et al. 1993). This tolerance to environmental variability, along with their high fecundity (Duponchelle et al., 1998), rapid growth rates (Mair, 2000; Liti et al. 2005) and omnivorous feeding habits (El-Sayed, 1999) further contribute to successful invasions in

estuaries. Mozambique Tilapia, for instance, was reported that it is among the 100 of the world's worst invasive alien species (Lowe et al., 2000). Nile Tilapia is another example that has successfully invaded ecosystems worldwide (Courtenay, 1997; Crutchfield, 1995).

Nonnative fish introductions disrupt ecosystem processes and can drive native species to local extinction (Zambrano et al., 2006). The lack of natural competitors in new ecosystems allows invasive species to be successful and resistant enough to survive in a foreign environment (Sutherst, 2000). A clear understanding of the status and behavior of invasive species is an important requirement for a successful management of such impacted systems (Laurenson and Hocutt, 1986). Consequently, invasions are the main concern for conservationists. Identification of causes that raise or promote an invader's success is one of the first steps for preventing and/or fighting against invasions (Linde et al., 2008). A large number of studies are therefore investigating fish species invasions with the aim to identify suitable habitats and to coordinate management plans. The conceptual findings and spatio-temporal predictions of these studies contribute to the early detection and elimination of invasive species to reduce their negative impacts. Therefore, understanding environmental factors effective on the spatial distribution of invasive species is crucially important to monitor them through time.

Remote sensing data are now available in several spatial and temporal resolutions and can help to develop environmental models. LANDSAT-5 Thematic Mapper (TM) and following LANDSAT-7 Enhanced Thematic Mapper Plus (ETM+) sensors have been providing near-continuous multispectral coverage with 16 day temporal resolution since 1982. This remarkable temporal coverage supplies the perfect data set for studies of natural resources for improved management (Moran et al., 2001), and contains thermal infrared (LANDSAT-5 TM: band 6, LANDSAT-7 ETM+: band 6.1) data which can be transformed to temperature. Consequently, distributions of invasive species

controlled by temperature have a great potential to be monitored by LANDSAT-5 TM and LANDSAT-7 ETM+ data.

Suez Canal, connecting the Mediterranean Sea with the Red Sea, opened some new migration routes for fish in 1869. Furthermore, fish introduction such as Nile Tilapia (*Oreochromis niloticus*) into some of the lakes contributed to successful invasions of Tilapia species in some of the estuaries of Mediterranean Sea. Köyceğiz Lake in Turkey, connected to Mediterranean Sea by a natural channel, is one of these areas. In Köyceğiz Lake, increasing Tilapia species populations have been observed since 1985 (Buhan, 1998). Due to the importance of this subject, detailed monthly field data were collected from the geo-referenced 4 stations on Köyceğiz Lake between January and December of 1993. This study aims to develop a model by utilizing these archival data including monthly fish numbers and temperature variables, and to monitor fish number change through time by applying the developed model on the thermal bands of LANDSAT-5 TM and LANDSAT-7 ETM+ satellite images taken on different dates.

2. Material and Methods

Köyceğiz Lake is located in the Mediterranean Region of Turkey (Figure 1a) and covers 52.85 km² area. Köyceğiz Lake ecosystem consists of six parts including (1) Köyceğiz Lake, (2) Sultaniye section of the lake, (3) a canal, (4) Sülüngür Lake, (5) lagoon, and (6) a pond (Figure 1b). The lake has a connection to Aegean Sea by a lagoon. In this study, we utilized an archival data collected from the 4 geo-referenced stations (Figure 1b) in Köyceğiz Lake between January and December of 1993. The archival data contains monthly fish number and temperature values that were determined by using (17, 20, 25, 28, and 32 mm mesh size and 500 m length) trammel nets and a multi-measuring device (YSI-33), respectively. This data includes 48 (12 months x 4 stations) observations for fish number and temperature variables.

The relationship between fish number and temperature variables was researched by applying

correlation (Pearson) analysis. After detecting significant positive correlation, polynomial regression analysis with the second order was applied to develop a model. SPSS software (SPSS, 2007) was employed for all statistical analyses. Obtained model was applied to the temperature (°C) raster maps developed from the thermal bands of a LANDSAT-5 TM image taken on 6 July 1995 and two LANDSAT-7 ETM+ images taken on 10 August 1999 and 12 July 2012.

To develop temperature raster maps, three satellite images (path/row: 179/34) were downloaded free from the web site of U.S. Geological Survey Earth Resources Observation and Science (EROS) Data Center. Cover area of the images was given in Figure 2a. All downloaded images have ortho-geocover attributes. Because of a technical problem in the scan line corrector (SLC) of LANDSAT-7 ETM+ satellite, images acquired after 31 May 2003 have gaps that need to be filled. For this reason, the gaps of the LANDSAT-7 ETM+ image, taken on 12 July 2012, were corrected by using a gap fill method (Bustillos, 2012) before analyzing. In ERDAS Imagine software (ERDAS, 2003), the thermal bands (LANDSAT-5 TM: band 6, LANDSAT-7 ETM+: band 6.1) of three satellite images were subset to obtain the area of interest (AOI) by using a vector AOI that was created from the map of Köyceğiz Lake (Figure 1b). Consequently, three subset images of the thermal bands that belong to three dates were created (Figure 2b).

Subset images of the thermal bands were transformed to point data in ArcGIS (version: 9.3.1) software (ESRI, 2005) by using conversion tools (from raster to point).

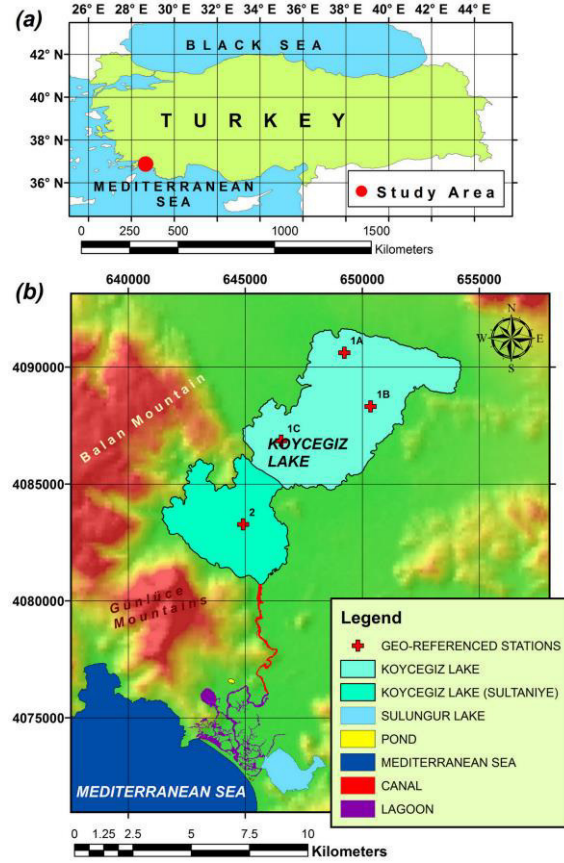


Figure 1. (a) Geographic position of the Köyceğiz Lake in Turkey (projection: geographic WGS1984), and (b) sampled geo-referenced stations (1A, 1B, 1C, and 2) within the main parts of the study area (projection: UTM, zone: 35N)

Şekil 1. (a) Köyceğiz Gölünün Türkiye'deki coğrafi konumu (projeksiyon: coğrafi WGS1984) ve (b) çalışma alanının ana bölümleri içinde örneklenen jeo referans istasyonları (1A, 1B, 1C ve 2) (projeksiyon: UTM, bölge: 35N)

Geographic reference (X and Y) values were assigned to the generated point data by using data management tools of ArcGIS. To prevent calculating errors, points that have zero digital numbers (DN) were deleted. Then, the final point data were exported to Microsoft Excel software, and the cell values as radiance were calculated by using Spectral Radiance Scaling Method (Coll et al., 2010) as follows:

$$CV_{R1} = ((LMAX_{\lambda} - LMIN_{\lambda}) / (QCALMAX - QCALMIN)) * (QCAL - QCALMIN) + LMIN_{\lambda}$$

Where: CV_{R1} is the cell value as radiance; $QCAL$ is band-6 pixel (DN) value, $LMIN_{\lambda}$ is spectral radiance scales to $QCALMIN$ ($LMIN_{\lambda} = 1.2378$), $LMAX_{\lambda}$ is spectral radiance scales to

$QCALMAX$ ($LMAX_{\lambda} = 15.303$), $QCALMIN$ is the minimum quantized calibrated pixel value (typically = 1); $QCALMAX$ is the maximum quantized calibrated pixel value (typically = 255).

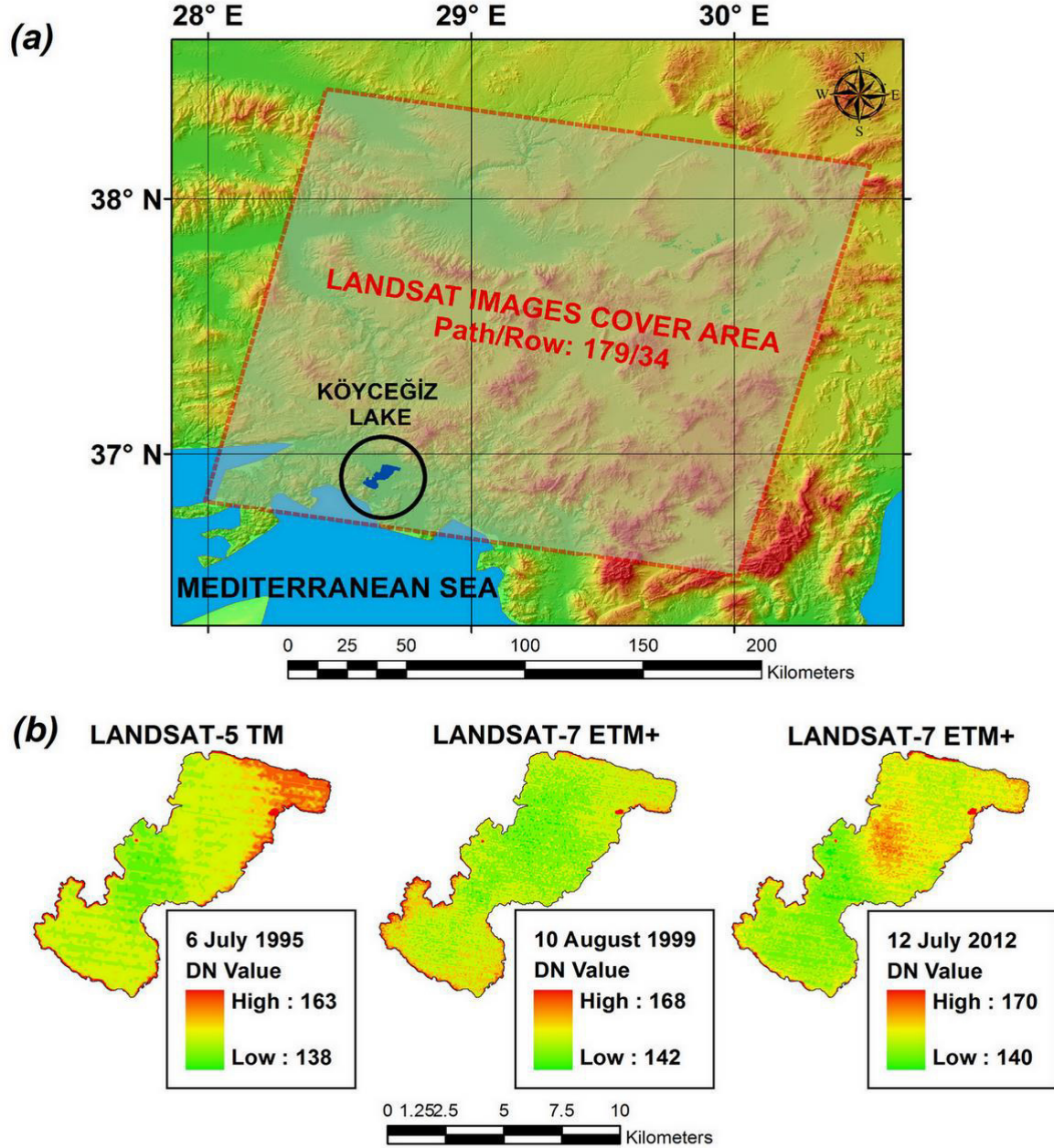


Figure 2. (a) Cover area of LANDSAT images (projection: geographic WGS1984), and (b) the subset thermal band (LANDSAT-5 TM: band 6, LANDSAT-7 ETM+: band 6.1) Digital Number (DN) values of three different dates (projection: UTM, zone: 35N)

Şekil 2. (a) LANDSAT görüntülerinin (projeksiyon: coğrafi WGS1984) kapladığı alan ve (b) subset edilmiş termal bandı (LANDSAT-5 TM: bant 6, LANDSAT-7 ETM +: bant 6.1) Üç farklı tarihin Dijital Numara (DN) değerleri (projeksiyon: UTM, bölge: 35N)

The calculated cell values as radiance were converted to temperature as Kelvin ($^{\circ}\text{K}$) in Excel software. The formula to convert radiance to temperature ($^{\circ}\text{K}$) without atmospheric correction is:

$$T = K_2 / \ln((K_1 * \varepsilon / CV_{R1}) + 1)$$

Where: T is temperature as Kelvin ($^{\circ}\text{K}$); CV_{R1} is cell value as radiance; ε is emissivity (typically = 0.95), K_1 is the fixed value (607.76 for LANDSAT-5 TM, 666.09 for LANDSAT-7 ETM+), K_2 is the fixed value (1260.56 for LANDSAT-5 TM, 1282.71 for LANDSAT-7 ETM+) (Coll et al., 2010). Using the following formula, Kelvin ($^{\circ}\text{K}$) values were converted to Celsius ($^{\circ}\text{C}$) in Excel software.

$$^{\circ}\text{C} = ^{\circ}\text{K} - 273.15$$

After calculating temperature values as Celsius ($^{\circ}\text{C}$), point data were converted to temperature raster maps by using conversion tools (from point to raster) in ArcGIS. Then, the developed model was applied to three temperature raster maps in order to predict Tilapia fish numbers. Consequently, fish number maps were developed for three different dates (6 July 1995, 10 August 1999, and 12 July 2012). The resolutions of three fish number maps were increased from 30 m to 1 m by following an explained method (Dogan et al., 2009). Finally, fish number for trammel net data was standardized to Catch Per Unit Effort (CPUE) as abundance per trammel net in a day (24 hours). Using spatial analysis tools (map calculation functions) of ArcGIS software, CPUE maps were developed by dividing the fish number to length of net (500 m).

3. Results

Archival data containing 48 observations of fish number and temperature variables was summarized in a graph (Figure 3a). A sudden jump in the number of fish started from 17.4 $^{\circ}\text{C}$ and increasing fish numbers with the increasing temperatures were clearly observed at temperatures between 19.0 and 29.4 $^{\circ}\text{C}$. Decreasing temperature and fish number also showed in parallelism after 29.4 $^{\circ}\text{C}$ that is the

highest temperature within 48 observations. The result of polynomial regression analysis with the second order showed that there is strong relationship ($R^2=0.8835$) between temperature and fish number variables. The developed regression model was given in Figure 3b.

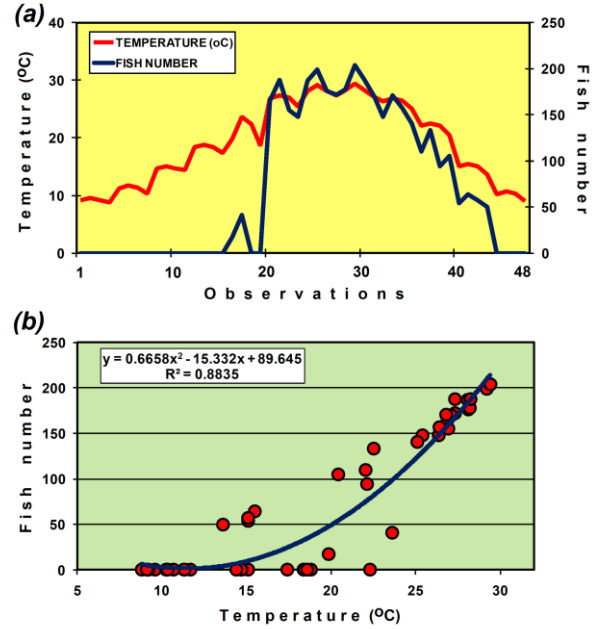


Figure 3. (a) Graph of archival data containing 48 observations, and (b) developed model, scattergram and polynomial trend line in the second order (NOTE: y is dependent variable (fish number) and x is the independent variable (temperature) in the developed model)

Şekil 3. (a) 48 gözlem içeren arşiv verilerinin grafiği ve (b) ikinci sıraya göre gelişmiş model, scattergram ve polinom eğilim çizgisi (NOT: Geliştirilen modelde y bağımlı değişken (balık sayıları) ve x bağımsız değişken (sıcaklık))

Temperature raster maps, developed from LANDSAT-5 TM and LANDSAT-7 ETM+ thermal bands, were shown in Figure 4a. As it was seen in Figure 4a, temperature varied between 27.3 and 37.5 $^{\circ}\text{C}$ on 6 July 1995. These values reached to 38.3 and 47.0 $^{\circ}\text{C}$ on 10 August 1999. Finally, temperature values changed between 37.3 and 48.0 $^{\circ}\text{C}$ on 12 July 2012. Among the three time periods, the lowest temperature was observed as 27.3 $^{\circ}\text{C}$ on 6 July 1995, and the highest temperature was determined as 48.0 $^{\circ}\text{C}$ on 12 July 2012. In spatial point of

view, temperature values were found higher in the northeast and southwest shores of the lake in 1995 and 1999. However, the middle of the lake began to heat up and joined to these areas in 2012. Consequently, with increasing amounts of temperature, increases in the heated areas were observed. This situation is a result of global warming.

Fish number maps, derived from the developed model, produced the parallel results to the temperature maps due to the strong ($R^2=0.8835$) relationship between temperature and the number of fish (Figure 4b). Fish numbers changed between 173-273 and 483-667 on 6 July 1995 and 10 August 1999, respectively. These values

reached to the values between 446 and 654 on 12 July 2012. Among the three time periods, the lowest and the highest fish numbers were observed as 173 and 667 on 6 July 1995 and 10 August 1999, respectively. In spatial point of view, fish numbers were found higher in the northeast and southwest shores of the lake in 1995 and 1999. In 2012, the middle of the lake joined to the areas where fish numbers are high. CPUE maps, developed by dividing the fish number to length of net (500 m), were shown in Figure 4c.

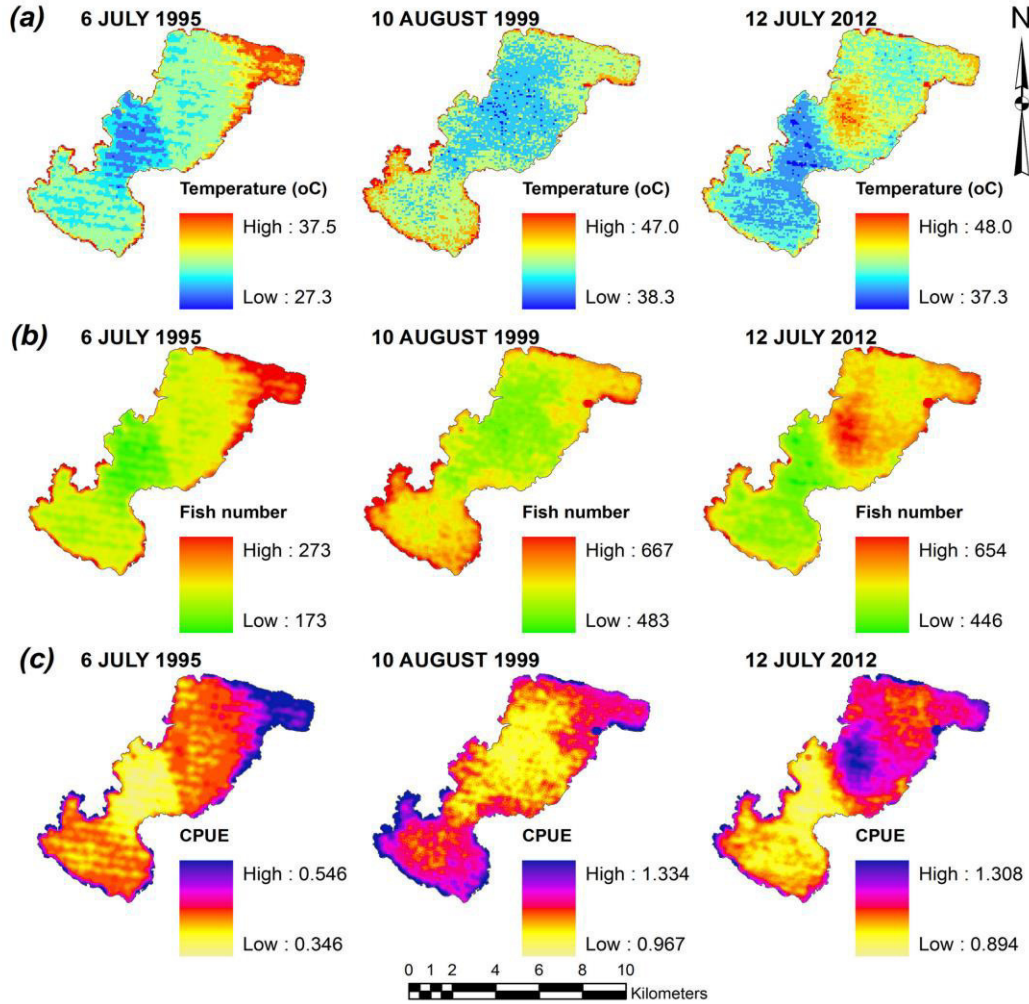


Figure 4. (a) Temperature, (b) fish number, and (c) CPUE raster maps

Şekil 4. (a) Sıcaklık, (b) balık sayıları ve (c) CPUE raster harita

Consequently, CPUE maps produced the parallel results to the fish number maps. Among the three time periods, the lowest and the highest CPUE values were observed as 0.346 and 1.334 on 6 July 1995 and 10 August 1999, respectively. Increasing CPUE values with the increasing temperatures were observed from 1995 to 2012.

4. Discussions and Conclusions

The temperature is one of the key factors that can drive species survival. Changes in temperature will most likely stress the ecosystems and give a chance to invasions (Dukes and Mooney, 1999; Simberloff, 2000). Consequently, the impact of climate change and increasing average world temperatures can have a profound influence on species' geographical ranges (Febry and Lutz, 1987; Avella et al., 1993). In aquatic ecosystems, an increase in water temperature causes a decrease in dissolved oxygen that is the main reasons of high physiological demands and stress (Poff and Allan, 1995; Jackson et al., 2001). However, Tilapias are thermophilic fish, and their geographic distributions have been limited by the low temperatures (Hauser, 1997). They quickly grow and reproduce at the appropriate temperatures of the year, and temperature drops can be fatal. It was reported that *Tilapia zillii* withstands to 13°C during two weeks, begins to take food at 11.2 °C, and has the lower tolerance limit at 6.5°C (Chervinsky, 1982; Caulton, 1982). The lowest reproducing temperature was reported as 20°C for *Tilapia zillii*, *Oerochromis aureus*, *Oerochromis niloticus* (introduced), *Oerochromis galilaeus* (Hauser, 1997; Chervinsky, 1982; Caulton, 1982; Jalabert and Zohar, 1982). Parallel to the literature, we found that temperature is highly effective on the invasive Tilapia fish populations in Köyceğiz Lake ecosystem. Strong positive correlation (0.88) between fish numbers and temperature showed that Tilapia fish

populations are controlled by temperature. Modelling this relationship, calculation of the number of fish became possible by using temperature data. Thus, our results showed that fish numbers can be predicted for different dates if reliable temperature data are available.

LANDSAT image archive has been opened to all kinds of users by Earth Resources Observation and Science Center (EROS) of United States Geological Survey (USGS). This unique archive contains reliable satellite images that have appropriate spatio-temporal and spectral resolutions for monitoring studies (Moran et al., 2001). Robust temperature data that belong to different dates can be obtained by utilizing LANDSAT thermal bands and can be converted to temperature raster maps (Coll et al., 2010). Therefore, LANDSAT data is very important for the mapping process of invasive species driven by temperature. In this study, we predicted and mapped the numbers and CPUE values of invasive Tilapia fish (*Tilapia spp.*) by applying our model on the temperature maps derived from LANDSAT-5 TM and LANDSAT-7 ETM+ images taken on 6 July 1995, 10 August 1999 and 12 July 2012. Interpretation of the temperature, fish number and CPUE maps showed that there is an increase in all variables in the investigated time period (1995-2012). Temperature increased 10.5°C between 1995 and 2012. Parallel to this increase, fish number values increased from 273 to 654, and CPUE values increased from 0.546 to 1.308. Overall results proved the invasive character of Tilapia fish (*Tilapia spp.*), and showed their spatial distributions in the Köyceğiz Lake through time.

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