

Invasion history and distribution of the aquatic alien *Elodea canadensis* (*Hydrocharitaceae*) in Turkey

Nursel İkinci (✉ nursel.ikinci@gmail.com)

Bolu Abant İzzet Baysal University <https://orcid.org/0000-0002-6435-5869>

Research Article

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Abstract

Submerged macrophyte *Elodea canadensis* Michx. is a non-native species to Turkey where it was first recorded in 1982. In this study, we aim to provide the current distribution of *E. canadensis* in Turkey with notes on its invasion history and ecology. We performed field studies to measure the physical and chemical parameters of the invaded lakes. Our study is based on new field works, herbarium specimen examination and literature survey. As a result of our findings, *E. canadensis* has invaded 15 wetlands in eight water basins of Turkey. Eleven of the invaded wetlands, including the largest freshwater lake of Turkey have protection forms ranging from national parks, nature parks to nationally/locally protected areas. Type of the wetlands are also diverse, like drainage canals, ancient pools, karstic, crater, tectonic and alluvial set lakes with trophic status from oligotrophic to eutrophic. Physico-chemical parameters measured in seven invaded wetlands are as follow: Water temperature between 15.5–22.3°C, pH between 7.1–8.6, dissolved oxygen as 3.7–8.8 mg l⁻¹, electrical conductivity as 230–610 µS cm⁻¹, salinity between 0.1–0.29 ppt, and ammonium as 0.25–0.74 mg l⁻¹. The altitude range of the colonized wetlands is between sea level and 2100 m a.s.l. *Elodea canadensis* forms single species stands in many sites, but we could totally record 22 accompanying macrophyte taxa in species rich habitats. Here we present the most comprehensive distribution and ecology data for *E. canadensis* in Turkey which could be used for further research and management to understand its future spread and effect on native vegetation.

Introduction

Alien invasive aquatic species are a serious environmental issue with numerous ecological impacts. They can cause severe disturbance of aquatic ecosystems since they have rapid reproduction by means of several dispersal vectors like long-lasting vegetative fragments. Invasive species generally have wide tolerance to abiotic factors. In terms of biotic interactions, they have competitive advantage (resource acquisition) over native species and can displace them in short time (Fleming and Dibble 2015). They have the capacity to adversely affect the biological diversity in an area by reducing the diversity and abundance of native species. They may cause extinction of species or altering the genetic diversity of the populations. Additionally, they can modify the trophic hierarchy and overall habitat properties (Montagnani et al. 2022). They can cause economic and health damages. Increasing human activities promote invasive species distribution by helping them to cross biogeographic barriers (Montagnani et al. 2022).

Elodea canadensis Michx. (Canadian waterweed, *Hydrocharitaceae*) is a submerged perennial aquatic plant. It can grow in various types of habitats but favors mesotrophic to eutrophic, relatively slow flowing inland freshwater bodies like ponds, lakes, ditches, irrigation canals, and slow-moving rivers (McGavigan 2017). In rare cases, it can also grow in fast-flowing waters (Lansdown et al. 2016). The species can live in different depths, from shallow waters to 4 meters deep (Mjelde et al. 2012). According to Zehnsdorf et al. (2015), *E. canadensis* can manage to live at higher altitudes. It is not vulnerable in terms of grazing (Zehnsdorf et al. 2015). As in the case of most macrophytes, it is easily fragmented and disperses effectively through vegetative means and the fragments have high survival rate (Cook and Urmi-König 1985; Barrat-Segretain et al. 2002). Under optimal growth conditions it can form dense monospecific stands resulting in reduction in temperature and oxygen concentrations of water and decomposition increases nutrient loading (Heikkinen et al. 2009). In northern Europe, dense populations of *E. canadensis* may change the ecosystem of the entire lake and cause the water to become hyper-eutrophic and muddy (Heikkinen et al. 2009). Bubíková et al. (2021) indicated that the relevés with higher *Elodea* abundance had lower species richness and beta diversity. *Elodea canadensis* is known to produce allelopathic compounds, which may contribute to its invasiveness (Fleming and Dibble 2015). It can establish dense single species stands and take over as the dominant species. The study of Liu et al. (2021) showed that warming enhances growth of *E. canadensis*. It can withstand moderately high light levels but not frost (Cook and Urmi-König 1985; Barrat-Segretain et al. 2002). It can also be an early colonizer of new or disturbed habitats (Simpson 1984). Heikkinen et al. (2009) reported that after *E. canadensis* became established in a particular waterbody, a cyclical trend frequently developed. The species reaches a pest status during the first 3–4 years, at which point it can effectively exclude other macrophytes. However, after the subsequent 3 to 10 years, populations frequently begin to progressively drop, and the species subsequently persists as a small remnant population or may go extinct for a while (Heikkinen et al. 2009). Prokopuk and Zub (2019) also reported that after its first record in 1984, *E. canadensis* showed regressive changes in its distribution in the last two decades in Ukraine.

Elodea canadensis is native to North America. Outside its native distribution area, it was reported from Australia, New Zealand, Oceania, Africa, South America, Central America and Caribbean, Asia, and most of Europe (Duenas-Lopez et al. 2018). It is generally accepted that *E. canadensis* first recorded from UK in 1836 despite the presence of some doubtful earlier reports (Simpson 1984). Later, it spread eastwards to the rest of Europe and quickly became the most widespread alien aquatic species in Europe (Hussner 2012). Its dispersal in Europe is by vegetative fragmentation (McGavigan 2017). *Elodea canadensis* is among the most common invasive aquatic plant species in Russia (Leostrin and Pergl 2021). Although very widespread in Russia, there is no confirmed record of it from the southern parts of the Greater Caucasus. However, it is found in 10 South Eastern European countries (Lansdown et al. 2016). *Elodea canadensis* herbarium specimens were first collected from Greece in 2014 from the Lake Great Prespa located at the northwestern corner of the country (Poulis and Zervas 2017). Assyov and Petrova (2012) showed that in addition to other parts of Bulgaria, *E. canadensis* has a distribution along the Turkish border.

Herbarium specimens provide us valuable information about the past distribution of plants. The first herbarium specimens of *E. canadensis* from Turkey were collected in 1982 (Altınayar and Onursal 1982). Subsequently, all the records prior to 1990 were from the Meriç-Ergene River basin in European Turkey. Starting from 1991, the species started to be observed in Asian part of Turkey. However, 40 years after its first invasion record, our knowledge about the current distribution range of *E. canadensis* in Turkey is limited. Even recently published Illustrated Flora of Turkey (Leblebici 2018) gives only two localities for the species, mainly because it is under-collected and represented by few specimens in herbaria. Therefore, in this study we aim to provide the distribution of *E. canadensis* in Turkey in detail based on new field works, herbarium specimen examination and literature survey. We provide new colonization sites for the first time here. In addition, we aim to determine the physical and chemical parameters of the water bodies where the species grows. As a result, we could contribute to understanding of the colonization dynamics and ecology of *E. canadensis* in Turkey.

Materials And Methods

In order to reveal the distribution of *E. canadensis* in Turkey, field studies were performed during the growth season of the plants between 2015 and 2021. Totally, 145 lentic and lotic wetlands were surveyed throughout Turkey. Macrophyte sampling was carried out by wading and walking along the littoral zone of the water bodies. In non-wadeable sites macrophytes were collected using a rake. Herbarium specimens were prepared from each sample and stored at AIBU Herbarium. Additionally, major Turkish herbaria (ANK, AEF, HUB, GAZI, ISTE, ISTO, ISTF, KNYA, EDTU, EGE, VANF, NGBB, CNH, AIBU, DUOF) were visited and inquired for the presence of any *E. canadensis* record. The herbarium acronyms are given according to Index Herbariorum (Thiers 2022). Digitized herbarium specimens in world herbaria were searched through online databases (<https://www.gbif.org>, JSTOR's Global Plants database, RBGE herbarium catalogue and <https://turkiyebitkileri.com/tr>) for any record or observation from Turkey. Moreover, data were collected from published sources (floristic checklists, floras, and other publications reporting presence of *E. canadensis*). Table 1 lists all the localities where *E. canadensis* has been recorded from Turkey until now.

We measured the physical and chemical parameters of the water bodies where *E. canadensis* was sampled. We conducted in-situ measurements of the environmental parameters using a portable multi-probe YSI-Professional Plus. Single measurements were made per site for physicochemical variables, and we applied the same sampling strategy to all wetland types. Average measurement depth was one meter, but we did measurements at depths less than one meter since the species was also growing in shallower water bodies. Sampling times are given on Table 2. The measured environmental variables were dissolved oxygen concentration (DO, mg L⁻¹), water temperature (Tw, °C), electrical conductivity (EC, µS cm⁻¹), pH, total dissolved solids (g L⁻¹), salinity (ppt) and ammonium (mg L⁻¹). The Magellan eXplorist 610 was used to record the altitude and the coordinates. Environmental parameters and abundances were assessed at random areas where the species was collected. The quadrats have a surface area of about one m². We calculated the abundance visually and noted the percentage of each species' range that was occupied. Abundance at each site was assigned a semi-quantitative category using an adapted ACFOR scale with five categories: Abundant (>80% cover), common (61–80%), frequent (31–60%), occasional (5–30%), and rare (< 5%) (Firth et al. 2015). The estimated abundance values were converted to numerical scores from 1 to 5.

Other than our collections and measurements, in Table 2, we also provide the physical and chemical parameters of the water bodies where *E. canadensis* observations/collections and measurements were made simultaneously by three previous research. In each of these previous research different parameters were measured. Therefore, some of the parameters are missing for certain lakes in Table 2. The number of measurements and the sampling months are also different. Altınsaçlı and Altınsaçlı (2005) did water chemistry measurements in Eflatun Pınar in December 1999 and February, May and July of 2000. Awche (2019) performed the physicochemical measurements of waters in Lake Beşgöz in June, August, September 2018 and in January and March of 2019. Ersoy and Turan (2019) measured the water chemistry parameters at three stations in Sapanca lake during July and August of 2016 and 2017 and they provided the mean values of the measurements which we listed in Table 2. We also give the average values in Table 2. for Lake Beşgöz and Eflatun Pınar.

Results

Our study provides the current distribution of *E. canadensis* in Turkey based on new field works in 145 waterbodies across Turkey, herbarium specimen examinations, and published literature. As a result, we recorded *E. canadensis* from 15 water bodies in eight provinces of Turkey (Table 1 and Fig. 1). These wetlands are in eight water basins in the western half of Turkey. The invaded wetlands can be found in all biogeographical regions of Turkey, namely Mediterranean, Anatolian and Black Sea. The first published record of *Elodea canadensis* in Turkey dates back to 1982 (Altınayar and Onursal 1982). This record was from Edirne province in Thrace region (European Turkey) and later it was collected from several other wetlands in this province (Seçmen and Leblebici 2008). Regarding Asian Turkey, *E. canadensis* was first recorded in a study conducted to describe the epiphytic and epilithic algae found in Lake Beşgöz in Konya province in 1991 and 1992 (Akköz et al. 2000). Recent studies conducted in 2018 and 2019, showed that the species was still growing in the same lake (Awche 2019). Lake Beşgöz is part of the Sakarya basin. In 1999, the species was observed in Eflatun Pınar, an important archeological site in Konya closed basin (Altınsaçlı and Altınsaçlı 2005). Later, *E. canadensis* was collected from the fourth largest lake of Turkey, Lake Eğirdir in 2005 and then the connected Lake Kovada in 2010 (Kesici et al. 2009, 2012). In 2011 and 2015, *E. canadensis* was collected from the third largest lake of Turkey, Lake Beyşehir. The lake is part of two national parks, Beyşehir and Kızıladağ. The former being the largest national park in Turkey. In 2016, *E. canadensis* was collected from Işıklıgöl (Denizli), from Eğrigöl (Antalya) and Dipsiz Göl (Seydişehir, Konya). All these lakes belong to different water basins (Table 1). Again in 2016 and 2017, the species was observed in Lake Sapanca in Sakarya basin (Ersoy and Turan 2019). Another new record was found in Emre Lake (Afyonkarahisar) belonging to a new basin, namely Akarçay in 2019 (pers. comm. and Türkiye Bitkileri 2022). Finally, the latest spread of the species was recorded in Lake Abant in 2020. This lake is found in northwestern Turkey (Fig. 2-4), belonging to Batı Karadeniz basin (western Black Sea). In this lake within the two years of period *E. canadensis* formed dense single species spots (Fig. 3). We suggest that Lake Abant was invaded after 2017, because of our previous knowledge of the aquatic vegetation of the lake and its surrounding including 2017.

In terms of altitudinal distribution of *E. canadensis* in Turkey, we see a gradient from sea level to c. 2100 m a.s.l. (Table 1). Lake Gala national park is at the sea level and Lake Eğrigöl in Central Taurus Mountains in Antalya province is at 2078 m a.s.l. Type of the inhabited wetlands are various, ranging from artificial water bodies like irrigation and drainage canals in Edirne province (Table 1) to tectonic lakes (Lake Abant, Kovada Lake, Eğirdir Lake, Lake Beyşehir, Lake Sapanca, and Işıklı Göl), karstic lakes (Dipsiz Göl) and crater lakes (Eğrigöl). There are also alluvial set lakes like Gala Lake. However, *E. canadensis* has no record from rivers in Turkey

According to our findings *E. canadensis* can grow as monospecific stands or with other macrophyte species. In Table 2, we provide the list of other macrophyte species growing together with *E. canadensis* in Turkey. Among these species *Ranunculus lingua* L., *Schoenoplectus lacustris* (L.) Palla, *Phragmites australis* (Cav.) Trin. ex Steud. and *Equisetum* sp. are emergent. The remaining 18 taxa are submerged or floating. The most common co-occurring taxa are *Ceratophyllum* sp., *Chara* sp., *Myriophyllum spicatum* L. and *Potamogeton natans* L. (Table 2). Some of the species are found only in single wetland together with *E. canadensis*. These are *Hippuris vulgaris* L., *Potamogeton trichoides* Cham. & Schldl., *Myriophyllum verticillatum* L., *Nuphar lutea* L., *Ranunculus lingua*, *Najas minor* All., *Phragmites australis*, and *Lemna* sp.

In Table 2, we provide the physical and chemical parameters of the waters in seven wetlands where *E. canadensis* grows. According to these results, water temperature (Tw) measurements vary between 15.5 °C and 22.3 °C. The highest Tw was measured in Işıklı Göl as 22.3 °C and the lowest in Eflatun Pınar as 15.5 °C. The pH interval of the water bodies where *E. canadensis* was collected is 7.1 to 8.6. The highest measurement is from Lake Abant as 8.6 and the lowest value is from Dipsiz Göl. The lowest dissolved oxygen (DO) value was also measured from Dipsiz Göl (as 3.7 mg l⁻¹) and the highest from Lake Beşgöz as 8.8 mg l⁻¹. The lowest EC was measured in Dipsiz Göl as 230 µS cm⁻¹ and the highest in Işıklı Göl as 610 µS cm⁻¹. All the sampled habitats were freshwater lakes. The salinity values measured varied between 0.1 ppt and 0.29 ppt. The lowest ammonium level was measured in Eğrigöl as 0.22 mg l⁻¹ and the highest level was measured in Dipsiz Göl as 0.74 mg l⁻¹.

Discussion

The present study provides the current distribution of *E. canadensis* in Turkey with notes on its ecology and invasion history. Concerning the spread history of *E. canadensis* in Europe and in Turkey, the species was first recorded from Europe in British Isles in 1836 and later invaded whole Europe (Simpson 1984). According to Lansdown et al. (2016), it is naturalized in 10 South-Eastern European country including European Turkey. *Elodea canadensis* was first collected in Greece in 2014 from the Lake Great Prespa (Poulis and Zervas 2017). It is also naturalized in different parts of Bulgaria including the Turkish border. There are herbarium specimens from Bulgaria already collected in 1953 (gbif.org 2022). According to Lansdown et al. (2016), *E. canadensis* was probably introduced to Turkey from Bulgaria. We could not find any herbarium specimens or publications proving the presence of *E. canadensis* in the eastern and the southern neighboring countries of Turkey.

As for the spread rate of *E. canadensis* in Turkey, recent observations showed that it was non-aggressive in its first invaded habitats in European Turkey (pers. comm.). Until 2010, in nearly 30 years the species invaded wetlands in Edirne province and three lakes in Asian Turkey. However, after 2010 there is an increase in the spread rate with eight new lakes. We think this is mainly because of the nature of the earliest invaded habitats, which were irrigation and drainage canals as previous research indicated *E. canadensis* rarely grows in fast-flowing waters or if it is found grows only in low abundance (Duenas-Lopez et al. 2018). Similar spread pattern was observed in UK when the species was established in artificial water bodies like drainage canals (Simpson 1984). Heikkinen et al. (2009) also reported a decline in populations after its rapid growth in the early years of invasion in northern Europe. However, further invasions of *E. canadensis* in lakes of Asian part of Turkey indicated that it spread rapidly and became the dominant submerged species in few years. Prior to 1990's, another lake, Lake Gala in the European part of Turkey was colonized by *E. canadensis* (Altınayar 1988). Lake Gala is a shallow (depth varies between 2.2 m to 30 cm) eutrophic, alluvial set lake (Öterler et al. 2015). It is part of the Meriç River Delta and is 10 km away from the Aegean Sea where Meriç River reaches the sea. The lake is under high anthropogenic pressure due to agricultural runoff and industrial activities. Tokatlı (2017) detected high levels of toxic metal accumulations in the lake mainly brought by Ergene River, which is one the most contaminated river in Turkey. In our studies in 2016, we could not find *E. canadensis* in Lake Gala. Instead there was dense growth of *Nymphoides peltata* (S.G.Gmel.) Kuntze, *Potamogeton nodosus* Poir., *P. perfoliatus* L., *P. crispus* L. and *Stuckenia pectinata* (Bayındır and İkinci 2020b).

The earliest record of *E. canadensis* from Asian Turkey is from Lake Beşgöz (Konya province) in 1991 and 1992 (Akköz et al. 2000). In a later study conducted in 2018 and 2019, *Elodea* was again observed in the lake (Awche 2019). In that study, clearly lower number of algae species was recorded compared to the previous research (Awche 2019). The possible reason for the reduced algae species diversity could be the presence of *E. canadensis* in the lake for about 30 years. In their long-term study, Dembowska et al. (2021) also found a reduction in abundance and biomass of phytoplankton after the colonization and dominance of *E. nuttallii* in the lake they studied. Lake Beşgöz is a natural lake fed by five underground water and several other springs. The lake is used for irrigation and affected by agricultural runoffs. There are different types of agricultural activities in the vicinity of the lake and fish aquaculture in the connected canals. It is evaluated as eutrophic. Maximum water temperatures are between 16–18 °C during the summer months. This lake has the highest DO (8.8 mg l⁻¹) and the lowest ammonium values (0.25 mg l⁻¹) among the *E. canadensis* invaded habitats (Awche 2019). The lake was in the danger of drying out in the last years and it was cleaned in 2016 and all the littoral zone was destroyed.

The second record of *E. canadensis* from Asian Turkey was from Eflatun Pınar recorded in 1999 and 2000 (Altınsaçlı and Altınsaçlı 2005). Eflatun Pınar Hittite Water Monument dates back to 3200 years and has remained structurally and functionally intact until today. The sacred pool measuring 30 x 35 m is currently fed by an active cold-water spring (Bozdağ et al. 2020). Therefore, it has the lowest Tw as 15.5 °C. Altınsaçlı and Altınsaçlı (2005) indicated that the pool has a dense macrophyte growth and the dominant species was *E. canadensis*. *Ceratophyllum* sp. and *Chara* sp. and as emergent *Typha* sp. and *Juncus* sp. are the other macrophytes growing in the pool. They stated that the pool was oligotrophic. In the past, the spring and the pool were used as fish farm by the villagers but later it was prohibited (Altınsaçlı and Altınsaçlı 2005).

After its invasion in Lake Eğirdir in 2005, *E. canadensis* became the dominant submerged species in the lake within few years. This tectonic lake is connected to Lake Kovada where *E. canadensis* was reported in 2010 (Kesici et al. 2012). These two lakes were separated because of silt accumulation. Lake Kovada is a karst-tectonic lake and its surrounding area are national park. Zeybek et al. (2013) stated that Lake Kovada and the canal connecting to Lake Eğirdir were eutrophic. On the other hand, Lake Eğirdir was considered as oligotrophic in the past but their study indicated that it changed to mesotrophic. Other studies indicate that Lake Eğirdir became eutrophic after 2000's (Kesici et al. 2009). It was proposed that *E. canadensis* was introduced to Lake Eğirdir via aquarium escape (Kesici et al. 2009).

The first herbarium specimens of *E. canadensis* from the largest freshwater lake of Turkey, Lake Beyşehir were collected in 2011 and later in 2015. Water from the above mentioned Eflatun Pınar ancient pool is feeding the Lake Beyşehir and they are both in Konya water basin. Lake Beyşehir is located in a karst-tectonic depression. The trophic status of the lake has changed from oligotrophic to mesotrophic. The lake is fed by waters from the surrounding mountains, precipitation, and snowmelt. The use of water for irrigation purpose is the main cause of water level fluctuations (Şanlı et al. 2022). *Elodea canadensis* was reported from another nearby lake in Konya basin, Dipsiz Göl (Seydişehir, Konya), which is a high mountain karst lake (1684 m a.s.l.) in Taurus Mountain Ranges (Fig. 1). The lake has 3 m depth with 6 ha surface area.

In 2016, *E. canadensis* was collected from Lake Işıklı (Çivril, Denizli), which belongs to a different basin Büyük Menderes. Lake Işıklı has a maximum depth of 7 m, fed by groundwater and two branches of Upper Büyük Menderes and several other creeks. The area of the lake was formerly a tectonic depression filled with water during rainy seasons. In 1968, it was surrounded by barriers and became a dam lake mainly used for agricultural irrigation (Aygen and Balık 2005). Işıldar and Ercoşkun (2021) indicated that water level drops due to excessive usage of water for irrigation. Sewage from the surrounding settlements, heavy pesticide usage and wastewater from the nearby textile factories worsened the water quality of the lake and the lake was assessed as eutrophic. They also stated that in the last 30 years water level dropped by 8.3%.

Lake Eğrigöl (Central Taurus Mountains, Gündoğmuş, Antalya) with its elevation at 2078 m a.s.l. is found at the highest altitude where *E. canadensis* is collected from Turkey. The lake has 10 m maximum depth and 1.14 km² surface area. Ice cover in the lake may persist from October/November to May/June (Aygen et al. 2009). Eğrigöl is one of the two habitats for the rare macrophyte *Stuckenia filiformis* (Persoon) Börner in Turkey (Bayındır and İkinci 2020a; İkinci and Bayındır 2021). The lake was assessed as oligotrophic or oligo-mesotrophic in a study which measured water quality parameters in 2000 and 2001 (Kaymakçı-Başaran and Egemen 2006). However, our recent observations show that it is under increasing anthropogenic pressure due to stock farming and several touristic activities and heavy visitors. As a result, algal blooms are observed starting from early summer. *Elodea canadensis* is the dominant submerged macrophyte in the lake and forms single-species patches. Growing number of visitors may be the reason for the increased eutrophication of the lake and introduction of *E. canadensis*.

One of the latest records for *E. canadensis* is from Sapanca Lake where it was first collected in spring 2016 and later in 2017. The species spread rapidly and observed at several different parts of the lake (Ersoy and Turan 2019). Ersoy and Turan (2019) reported that *E. canadensis* was growing together with six other macrophyte species in this lake (Table 2). Sapanca Lake is an important tectonic lake, which supplies water for different purposes ranging from drinking water to industry (Ersoy and Turan 2019). It has a maximum depth of 55 m and it is fed by several creeks and groundwater. The lake is in a place with dense population and heavy industrial activities. According to Ersoy and Turan (2019), its water quality is deteriorating rapidly in the last years and experiences cyanobacterial blooms due to eutrophication.

According to our findings, the most recent invaded habitat for *E. canadensis* is Lake Abant (Bolu). The lake is part of the water basin Batı Karadeniz Havzası (Western Black Sea Basin), which is also a new basin for *E. canadensis*. Lake Abant is a botanically well-known national park. Starting from 1950's to today, there are many floristic studies conducted around the lake including aquatic plants (Wagenitz 1962; Türker and Güner 2003; İkinci 2022). Our studies about the aquatic flora of Bolu province between 1997 and 2017 revealed no *E. canadensis* in the area (İkinci 2000, 2011; İkinci and Güner 2007; İkinci and Bayındır 2019). We have found the species for the first time in July 2020 in Lake Abant. Our field works in 2021 showed that the species became the dominant submerged macrophyte in the lake in short time. Because of our detailed knowledge about the past aquatic flora of the lake, we think the invasion took place after 2017. As stated above, *E. canadensis* was collected from the nearby Sapanca Lake in 2016 which may be the source of invasion of Lake Abant. Other than this, Lake Abant visited by around 800 000 people yearly because it is an important touristic destination with many hotels and other activities. Therefore, the most probable introduction of *E. canadensis* can be passive transportation of vegetative fragments by different recreational activities of visitors and fishermen. Vegetative propagule transport by waterfowl is also possible. Water quality of this important national park is also deteriorating because the trophic status of the lake has changed from oligotrophic to mesotrophic recently (İkinci and Bayındır 2019).

In Turkey, we have recorded *E. canadensis* from sea level to c. 2100 m a.s.l. and in future we may expect to find it at higher elevations. *Elodea canadensis* can grow into dense stands under optimum growth conditions, which lowers water temperature and oxygen concentrations while increasing nutrient loading due to decomposition (Heikkinen et al. 2009). We did not measure extreme low or high DO levels from Turkish habitats. The lowest DO (3.7 mg l⁻¹) and also the lowest EC value (230 µS cm⁻¹) were measured from one of the alpine lake, Lake Dipsiz. This low DO value may be the result of our measurements only being taken in September. However, although they did the measurements in July, Topkara et al. (2009) also found the lowest DO value (as 4.8 mg l⁻¹) from Dipsiz lake among the 12 studied mountain lakes. Heikkinen et al. (2009), indicated that *E. canadensis* grows in eutrophic, calcium-rich, cool waters with a temperature range of 10 °C to 25 °C and a wide pH interval of 6.5 to 10. Water temperature interval for the Turkish habitats was between 15.5 °C and 22.3 °C and the pH interval was 7.1 to 8.6. The values are in accordance with the broad tolerance capability of the species. According to Heikkinen et al. (2009) under suitable conditions *E. canadensis* can form dense monospecific stands and became the dominant species. Bubíková et al. (2021) reported that when *Elodea* was in high abundance, lower species richness was recorded. One of the reasons for the reduction in species richness can be the allelopathic compounds produced by *E. canadensis* (Fleming and Dibble 2015).

Conclusions

As a conclusion, we report *E. canadensis* from 15 water bodies in Turkey belonging to eight water basins. Compared to some other European countries, the rate of spread in 40 years is not very high. Therefore, together with our recent observations on its first invaded habitats we can conclude that the species was not very aggressive in Turkey. The possible reasons can be that some of the human mediated introduction mechanisms like escape from botanic garden collections, aquarium trade, and growing the plant for scientific purposes and for phytoremediation were not so dense in Turkey as in those European countries. In terms of biological conservation, among the invaded wetlands in Turkey five are national parks and the remaining six are either nature parks or nationally/locally protected areas. Only four of the wetlands do not have any conservation status. One of the biggest dangers to biodiversity in protected areas around the world is biological invasions. *Elodea canadensis* can negatively alter the native aquatic vegetation in these protected wetlands causing biodiversity loss and displacing native species. This paper provides the available data on occurrence of *E. canadensis* in Turkey. However, only for some of the wetlands we have information about the effect of *E. canadensis* on native vegetation as many of the records are either single collections/observations or data based on studies of two years of period. Therefore, further studies are needed for a better understanding the long-term effect of *E. canadensis* on native vegetation. Predicting the future spread of an already naturalized species and its effects on the native vegetation can be very useful for management planning. As mentioned above, both eutrophication and warming promotes growth of *E. canadensis*. Therefore, we may expect further spread of the species. For effective

resource allocation to prevent its invasions and to guide development of policy responses, a greater knowledge of how invasions affect protected areas is essential. In this context, our study provides the most updated distribution of *E. canadensis* in Turkey with notes on its invasion history and ecology.

Declarations

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Conflict of interest: The corresponding author states that there is no conflict of interest.

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Tables

Table 1. The records of *E. canadensis* from Turkey in the order of the latest to the earliest collection or observation date. Collector number is given when present.

Locality	Basin	Altitude (m a.s.l.)	Voucher/Collector	Collection date	Source
Bolu: Abant Lake	Batı Karadeniz	1314-1336	N. İkinci 4909, 4913-14, 4919, 4922, 4926	26.08.2021	This study
Bolu: Abant Lake	Batı Karadeniz	1320	N. İkinci 4861	14.07.2020	This study
Bolu: Abant Lake	Batı Karadeniz	1320	N. İkinci 4868	27.07.2020	This study
Afyonkarahisar: İhsaniye, Emre Gölü	Akarçay	1150	A. Karataş	29.06.2019	Karataş (2019)
Konya: Sarayönü, Lake Beşgöz	Sakarya	1030	OAA Awche	2018-2019	Awche 2019
Sakarya: Sapanca Lake	Sakarya	c. 30	Ersoy & Turan	2016, 2017	Ersoy & Turan 2019
Denizli: Çivril, Işıklı Göl	Büyük Menderes	827	N. Bayındır 1226	19.06.2016	This study
Antalya: Gündoğmuş, Eğrigöl	Doğu Akdeniz	2078	N. Bayındır 1453	25.06.2016	This study
Konya: Seydişehir, Dipsiz Göl	Konya	1684	N. Bayındır 1454	9.09.2016	This study
Konya: Beyşehir, Beyşehir Gölü	Konya	1100	N. Bayındır 1046	19.06.2015	Leblebici 2018
Konya: Beyşehir	Konya	1120	A. Bakacak 109	2.05.2011	This Study
Isparta: Kovada Lake	Antalya	900	E. Kesici	June 2010	Kesici et al. 2012
Isparta: Eğirdir Gölü	Antalya	915	E. Kesici	May 2005	Kesici et al. 2009
Konya: Beyşehir, Eflatun Pınar	Konya	1150	Altınsaçlı & Altınsaçlı	1999, 2000	Altınsaçlı & Altınsaçlı 2005
Konya: Sarayönü, Lake Beşgöz	Sakarya	1030	C. Akköz	1991-1992	Akköz et al. 2000
Edirne: Enez, Gala Gölü	Meriç-Ergene	2	G. Altınay	1988	Altınay 1988
Edirne: Karaağaç, Bosna köyü yakınında, OR-4 Drenaj kanalı, Sulama kanalı	Meriç-Ergene	c. 40	Leblebici 4582	27.06.1984	Seçmen & Leblebici 1991
Edirne: center of KI, drainage canal, km 5 + 000	Meriç-Ergene	c. 40	Tülümen		Uotila 1984
Edirne: İpsala, İP-1-1 ve İP-1-2 yedek boşaltım kanalları	Meriç-Ergene	c. 20	G. Altınay		Altınay 1988
Edirne: Merkez Kİ-1 drenaj kanalı son kesimleri	Meriç-Ergene	c. 40	G. Altınay	27.07.1982	Altınay & Onursal 1982

Table 2. Physical and chemical parameters and the accompanying species at stations where *E. canadensis* was sampled together with measurements (+ indicates the presence of the macrophyte species in the specified wetland). Abundance is given for *E. canadensis*, which was calculated as indicated on Materials and Methods section. Details of the wetlands and vouchers can be found in Table 1. Sampling dates of three wetlands are given in Materials and Methods section.

Lake	Sampling Time	Tw (°C)	pH	DO (mg l-1)	EC (µS cm-1)	TDS (g l-1)	Salinity (ppt)	Ammonium (mg l-1)	Abundance	<i>Myriophyllum spicatum</i>	<i>Myriophyllum verticillatum</i>	<i>Potamogeton natans</i>	<i>Potamogeton berchtoldii</i>	<i>Potamogeton trichoides</i>	<i>Potamogeton perfoliatus</i>
Abant	26.08.2021	21.1	8.6	5.9	547	0.38	0.29	0.61	3	+	+	+			+
Işık Göl	16.06.2016	22.3	7.7	6.4	610	0.35	0.26	0.72	4					+	
Eğrigöl	25.06.2016	16.1	8.1	5.9	238	0.15	0.10	0.22	5			+			
Dipsiz Göl	09.09.2016	21.2	7.1	3.7	230	0.16	0.12	0.74	2			+			
Beşgöz		16.2	7.9	8.8	353			0.25		+					
Eflatunpınar		15.5	7.5	5.9	597		0.10								
Sapanca		17.6	7.5	8.6	265					+					

Figures

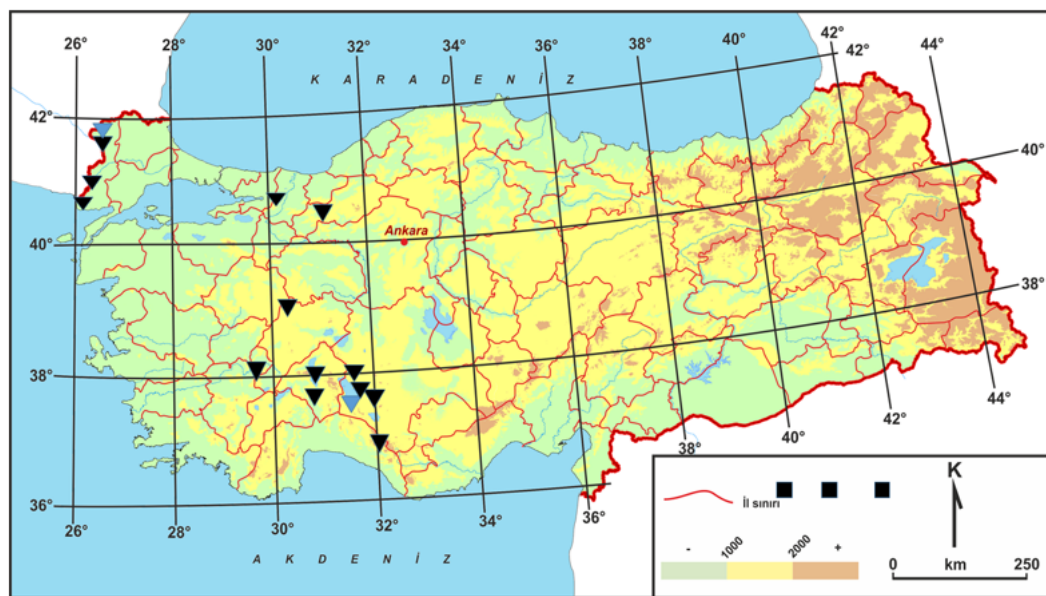


Figure 1

Distribution of *Eleodea canadensis* in Turkey. Blue inverted triangles are records cited in The Illustrated Flora of Turkey (Leblebici 2018)



Figure 2

One of the species rich habitats of *E. canadensis* (on the lower left corner) in Lake Abant (N. İkinci 4913)



Figure 3

Single-species spot of *E. canadensis* in Lake Abant (N. İkinci 4914)

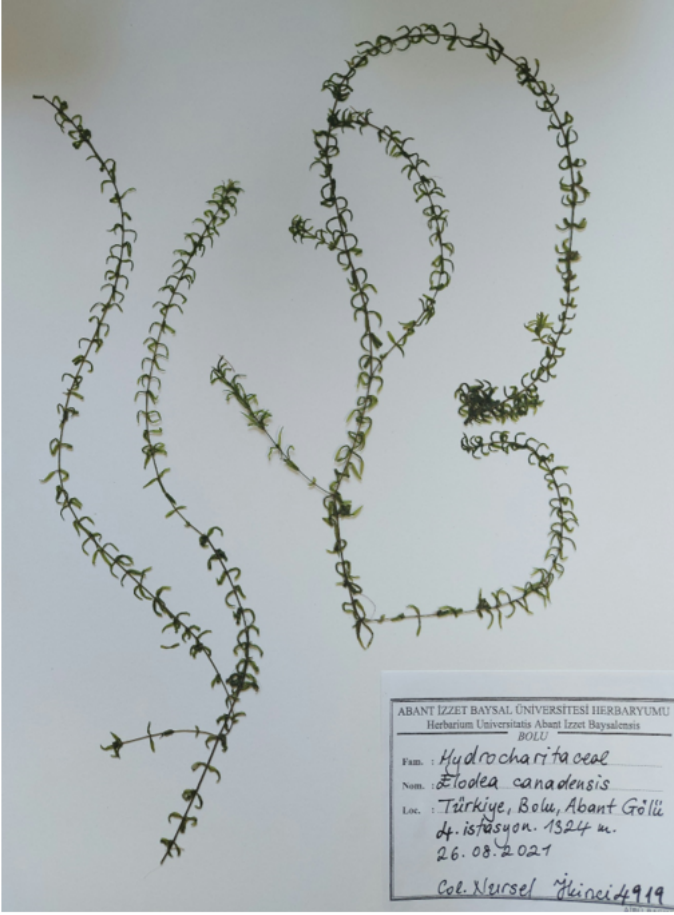


Figure 4

Herbarium specimen of *E. canadensis* from Lake Abant national park