Northernmost record of *Eleotris oxycephala* (Gobioidei: Eleotridae) based on a juvenile specimen from Akita Prefecture in northern Japan: range extension along the Sea of Japan coastline

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Abstract: The amphidromous fish *Eleotris oxycephala* Temminck & Schlegel, 1845 (Gobioidei: Eleotridae) is a temperate species, which is mainly distributed in southern Japan, southern Korea, Taiwan, and southeast China. In this study, a juvenile specimen of the species was collected from a channel flowing into the Yoneshiro River in Akita Prefecture, northern Japan. This is the first record of the species in Akita and represents the northernmost record for the species. Since no adult individual of the species was collected in this study, we conclude that the juvenile individual dispersed from the south via the Tsushima Current. In recent years, the species has been increasingly observed along the Sea of Japan coastline of Honshu, including Akita Prefecture. This northward range extension might be due to rising water temperatures caused by global warming.

Key words: geographical distribution, larval dispersion, northward range extension, tidal reach, western Pacific

Introduction

The genus *Eleotris* Bloch & Schneider, 1801, which belongs to the family Eleotridae (Perciformes: Gobioidei), is widely distributed in estuaries and freshwater streams in tropical, subtropical, and temperate zones (Pezold & Cage, 2002; Akihito et al., 2013; Guimarães-Costa et al., 2016; Mennesson et al., 2019). One of the northernmost distributional areas of the genus *Eleotris* is Japan, where the following four species are found: *E. oxycephala* Temminck & Schlegel, 1845, *E. acanthopoma* Bleeker, 1853, *E. melanosoma* Bleeker, 1853, and *E. fuscus* (Bloch & Schneider, 1801) (Akihito, 1967; Akihito et al., 2013).

*Eleotris oxycephala* is a temperate species and in addition to its distribution in Japan (from Ishikawa and Fukushima Prefectures in the north to the Osumi Islands in the south), is also found in Korea (Busan and Jeju Island), Taiwan, and southeast China (Oshima, 1919; Akihito, 1967; Akihito et al., 2013; Kuraishi, 2014; Kim et al., 2014; Meng et al., 2015; Yamakawa et al., 2021a). *Eleotris oxycephala* is an amphidromous fish (Xia et al., 2015) that has an oceanic pelagic larval stage, but lives in the brackish to freshwater areas of the lower reaches of rivers during its juvenile and adult stages (Suguro & Senou, 2006). In recent years, the species has been increasingly observed in areas of Japan at the northern limit of its currently recognized distribution (Yamakawa & Senou, 2015).

One hypothesized mechanism for this range extension is rising water temperatures caused by global warming (Yamakawa & Senou, 2015). However, there is still limited data on the nature and extent of the northward range extension of *E. oxycephala*. Consequently, more information about the status of *E. oxycephala* around and beyond its northern distributional limit is needed.

In September 2020, one juvenile *E. oxycephala* was collected from a channel in Akita Prefecture, northern Japan. This specimen is the first record of the species from the prefecture, and extends the previous distributional range of the species northward. We report detailed information about the specimen and the habitat where it was collected.

Material and Methods

A specimen of *E. oxycephala* was collected from a channel flowing into the lower reaches of the Yoneshiro River in Noshiro City, Akita Prefecture, northern Japan (Fig. 1; 40°13′29″N, 140°00′41″E) using a D-frame net (33 cm width × 30 cm height, mesh size: 2 mm) on 29 September 2020.

The specimen was stored frozen and then fixed in 10% buffered formalin. After fixation, the specimen was preserved in 70% ethanol. Taxonomic counts, measurements, and terminology followed Akihito (1967), Nakabo & Nakayama (2013), and Akihito et al. (2013). Counts and description of scales were difficult due to damage to the specimen, thus, they are not provided in this paper. Measurements were made to the nearest 0.1 mm by using a caliper. Both standard length (SL)
and total length (TL) were recorded. Measured values were expressed as a percentage of SL. The cephalic sensory organ was observed after staining the specimen with a cyanine blue solution. The specimen was deposited in the Kanagawa Prefectural Museum of Natural History (KPM-NI), Odawara City, Kanagawa Prefecture, Japan.

**Results**

*Eleotris oxycephala* Temminck & Schlegel, 1845  
[Japanese name: Kawa-anago]  
(Fig. 2)

**Material examined.** KPM-NI 64361, 21.4 mm SL, collected from a channel flowing into the Yoneshiro River in Ochiai-furuakudo, Noshiro City, Akita Prefecture, northern Japan, 40°13′29″N, 140°00′41″E, 29 September 2020, by U. Yamakawa.

**Description.** Dorsal-fin rays VI-I, 8; anal-fin rays I, 8; pectoral-fin rays 17 on both sides of body; pelvic-fin rays I, 5. Proportional measurements (as percentage of SL): TL 128.0; body depth at pelvic-fin origin 17.3; body width at pelvic-fin origin 18.2; head length 28.5; snout length 6.5; orbit diameter 6.1; interorbital width 7.5; postorbital length 15.9; upper jaw length 11.7; caudal-peduncle depth 11.2; caudal-peduncle length 23.4; first dorsal-fin base length 14.0; second dorsal-fin base length 15.0; anal-fin base length 13.1; pectoral-fin length 21.0; pelvic-fin length 11.2.

Body elongate, cylindrical anteriorly, and somewhat compressed posteriorly with a rather deep caudal peduncle. Head broad and somewhat depressed. Snout slightly sharp. Mouth oblique. Lower jaw slightly protruding than upper jaw, each posterior tip extends vertical line of anterior margin of eye and reaching below middle of pupil. Anterior nostril slightly posterior to upper lip, tubular, and its anterior tip reaching upper lip. Posterior nostril closer to anterior margin of eye, and simple pore, not tubular. Eye close to dorsal margin of head. Upper end of gill opening located slightly over origin of pectoral fin. Two dorsal fins, separated. First dorsal fin not elongated, sec-

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Fig. 1. Map showing localities where *Eleotris oxycephala* was recorded along the Sea of Japan coastline of Honshu, Japan. A. Map showing the locations of Japan, Korea, Taiwan, China, the Pacific Ocean, the Sea of Japan, and the East China Sea, and routes of the Kuroshio Current and the Tsushima Current. B. Enlarged map of the Sea of Japan coastline of Honshu, Japan. The black star (★) and black circles (●) show records in this study and previous studies, respectively. The numbers of the black star and black circles correspond to the Location No. in Table 1. These maps were created by editing the data obtained from Natural Earth (http://www.naturalearthdata.com/) by U. Yamakawa.

Fig. 2. A photograph of a juvenile specimen of *Eleotris oxycephala* (KPM-NI 64361, 21.4 mm SL) collected from a channel flowing into the Yoneshiro River, Akita Prefecture, northern Japan, on 29 September 2020. Photographed by H. Senou.
Northernmost record of *Eleotris oxycephala* from Akita, Japan


**Cephalic sensory system.** Preopercular pore absent. Posterior ends of upper and lower longitudinal rows of sensory papillae on opercle separated from each other. Rows of sensory papillae below eye transverse; transverse line 3, 4, and 5 below eye not extending beyond longitudinal row 11 (*sensu* Akihito, 1967).

**Coloration of the fixed specimen.** Background of head and side body grayish white. A lot of small melanophores fairly densely distributed from snout to caudal-fin base of side body and on underside of lower jaw. Two blackish longitudinal stripes extending from postorbital region to cheek. Dorsum and abdomen of body grayish white. Dorsum with numerous extremely small melanophores scattered irregularly and abdomen with numerous small melanophores scattered irregularly. Lower part of first dorsal fin translucent with scattered small melanophores (upper part of fin membrane damaged). First dorsal-fin spines translucent and tips from first spine to fifth spine black. Lower part of second dorsal fin translucent with some small melanophores (upper part of fin membrane damaged). Second dorsal-fin rays translucent. Fin rays of anal fin translucent (fin membrane of anal fin damaged). Caudal fin bearing dark brown mottled markings with broad transparent margin. Pectoral fins translucent with extremely small melanophores scattered irregularly on fin rays. Pelvic fins translucent.

**Habitat.** The specimen was collected from around the roots of the reed *Phragmites australis* (Cavanilles) Trinian ex Steudel, 1841, which was growing on the right side of the channel. The sampling site was located about 5 m upstream from the confluence with the lower reaches of the Yoneshiro River. The site was a tidal reach with little inflow of seawater. The salinity was about 0‰, the water depth was about 0.3 m, and the water temperature was 20.1°C at the time of collection. The riverbed had a cobble, sand, and mud substrate.

**Distribution.** *Eleotris oxycephala* is widely distributed in the western Pacific region, including Japan, Busan and Jeju Island in Korea, Taiwan, and southeast China (Oshima, 1919; Akihito, 1967; Akihito et al., 2013; Kim et al., 2014; Meng et al., 2015).

In Japan, *E. oxycephala* has been recorded from: Gunma, Tochigi, and Gifu Prefectures; along the Pacific Ocean coastline from Fukushima Prefecture to Kagoshima Prefecture; along the Sea of Japan and East China Sea coastline from Akita Prefecture to Kagoshima Prefecture; Tsushima Island; Kami-koshi Island in the Koshiki Islands; the coast of the Seto Inland Sea; and Tanegashima Island and Yakushima Island in the Osumi Islands (e.g., Matsushima & Kurata, 1954; Doutu & Fujita, 1959; Akihito, 1967; Kimura, 1989; Eda, 1994; Masuda & Suzuki, 1996; Aki & Yano, 1998; Ando, 1998; Ando, 1999; Fukagawa & Nakahara, 1999; Yamaguchi, 2003; Table 1. The details of records of *Eleotris oxycephala* from the Sea of Japan coastline of Honshu, Japan.

<table>
<thead>
<tr>
<th>Location No.</th>
<th>Prefecture</th>
<th>River, Lake, or Channel</th>
<th>Number of individuals</th>
<th>St. (TL)</th>
<th>Year of Collection</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Akita</td>
<td>channel flowing into the Yoneshiro River</td>
<td>1*</td>
<td>21.0 (27.4)</td>
<td>2020</td>
<td>This study</td>
</tr>
<tr>
<td>3</td>
<td>Niho River</td>
<td>in the Todoroki River system</td>
<td>1*</td>
<td>22.2 (7)</td>
<td>2020</td>
<td>Yamakawa et al. (2021a)</td>
</tr>
<tr>
<td>4</td>
<td>Shinobi River</td>
<td></td>
<td>3*</td>
<td>150 (7)</td>
<td>2003</td>
<td>Yamasato et al. (2003)</td>
</tr>
<tr>
<td>5</td>
<td>Dainboji River</td>
<td></td>
<td>1*</td>
<td>300 (6)</td>
<td>2000</td>
<td>Pascual et al. (2002)</td>
</tr>
<tr>
<td>6</td>
<td>channel flowing into Lake Kitagata</td>
<td></td>
<td>1*</td>
<td>18.0 (7)</td>
<td>2020</td>
<td>Yamakawa et al. (2023a)</td>
</tr>
<tr>
<td>10</td>
<td>Arai Channel flowing into Lake Kugashi</td>
<td></td>
<td>1*</td>
<td>2007</td>
<td>Fukui Coastal Nature Center (2011)</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Kyoto</td>
<td>Yura River</td>
<td>1*</td>
<td>250 (6)</td>
<td>2009</td>
<td>Maizuru Citizen Newspaper (2009)</td>
</tr>
<tr>
<td>14</td>
<td>Koyama River in the Sendai River system</td>
<td></td>
<td>1*</td>
<td>197 (6)</td>
<td>1998</td>
<td>Ando (1999)</td>
</tr>
<tr>
<td>16</td>
<td>Shinamane</td>
<td>Kido River in the Hii River system</td>
<td>1*</td>
<td>200 (6)</td>
<td>2010</td>
<td>Yamaguchi (2011)</td>
</tr>
<tr>
<td>17</td>
<td>Hori River</td>
<td></td>
<td>1*</td>
<td>28 (28)</td>
<td>2011</td>
<td>Tajii (2014)</td>
</tr>
<tr>
<td>20</td>
<td>Takataru River</td>
<td></td>
<td>1*</td>
<td>170 (222)</td>
<td>2010</td>
<td>Yamaguchi (2011)</td>
</tr>
</tbody>
</table>

1. The units are in mm.
2. = Specimen-based record.
3. = Fixation-based record.
4. = Live-based record.
5. = Record as an invasive species.
Kato, 2004; River Bureau, Ministry of Land, Infrastructure and Transport, 2006; Fujii, 2009; Yoshigou, 2009; Yamaguchi, 2011; Yasui et al., 2011; Fukagawa, 2012; Akihito et al., 2013; Tsuji, 2014; Kuraishi, 2014; Yamakawa & Senou, 2015; Yamakawa et al., 2020; Oyama et al., 2021; Yamakawa et al., 2021a; this study). Moreover, *Eleotris oxycephala* has been recorded as an invasive species in Saitama and Shiga Prefectures (Sato, 2017; Shiga Prefectural Fisheries Experiment Station, 2018). Details of the records of *Eleotris oxycephala* from the Sea of Japan coastline of Honshu are shown in Table 1 (i.e., prefectoral names, names of rivers, lakes, and channels, number of individuals recorded, SL and TL of recorded individuals, collecting years, and references).

As a side note, Dotu & Fujita (1959) stated that *Eleotris oxycephala* was distributed in Miyagi Prefecture based on Matsushima & Kurata (1954). However, although Matsushima & Kurata (1954) recorded *Eleotris oxycephala* from Tokyo, they did not describe the habitat of *Eleotris oxycephala* in Miyagi Prefecture. Therefore, Dotu & Fujita’s (1959) description of the distribution of *Eleotris oxycephala* in Miyagi Prefecture is considered to be erroneous. Moreover, two specimens of *Eleotris oxycephala* were recorded from Fukue Island in the Goto Islands (Hayashi et al., 1988). However, one specimen might be *E. acanthopoma*, not *Eleotris oxycephala*, judging from the specimen photo in Hayashi et al. (1988) and based on the following characteristics: anterior nasal tube long and its anterior tip extending beyond upper lip, three blackish longitudinal stripes extending from postorbital region to cheek, and two blackish spots on base of caudal fin (Yamakawa, unpublished). The other specimen is lost, and no photographs or detailed morphology are available in Hayashi et al. (1988). Consequently, it is impossible to re-verify whether the specimen is *Eleotris oxycephala* or not. Therefore, Miyagi Prefecture and Fukue Island were not included in the distributional range of *Eleotris oxycephala* described in this study.

**Remarks.** Some small whitish spots on underside of lower jaw of the specimen when alive, however, disappeared after fixation.

**Discussion**

The specimen collected in this study was identified as *Eleotris oxycephala* according to Akihito (1967) and Akihito et al. (2013) and based on the following characteristics: posterior tips of upper and lower jaws extend vertical line of anterior margin of eye, anterior nostril tubular and its anterior tip reaching upper lip, preopercular pore absent, posterior ends of upper and lower longitudinal rows of sensory papillae on opercle separated from each other, rows of sensory papillae below eye transverse, and transverse line 3, 4, and 5 below eye not extending beyond longitudinal row 11 (sensu Akihito, 1967).

"Distribution" section. Prior to this study, the northernmost observations of *Eleotris oxycephala* were from Ishikawa Prefecture, on the Sea of Japan coast of Japan and Fukushima Prefecture, on the Pacific Ocean coast of Japan (Kuraishi, 2014; Yamakawa et al., 2021a). Thus, the specimen collected from Akita Prefecture in this study represents the first record of the species in Akita and a new northernmost record, extending the known distributional range of *Eleotris oxycephala* on the Sea of Japan coast approximately 500 km north-eastward.

*Eleotris oxycephala* becomes sexually mature at more than 55.0 mm SL (Yamakawa et al., 2021b) and can reach up to 270 mm TL (Dotu & Fujita, 1959). The specimen collected in this study was 21.4 mm SL, therefore, it was regarded as a juvenile. In this study, no adult fish were collected. Moreover, the northernmost location along the Sea of Japan coastline of Honshu where mature-sized *Eleotris oxycephala* (≥ 55.0 mm SL) have been recorded is the Kuzuryu River system in Fukui Prefecture (except for records as an invasive species) (Table 1, numbers 7 and 8 in Fig. 1B). The winter water temperature in the lower reaches of this river system is about 7°C [e.g., 7.0°C in February 2020, Water Information System, Ministry of Land, Infrastructure, Transport and Tourism (2021a)]. In comparison, the winter water temperature in the lower reaches of the Yoneshiro River (sampled in this study) is about 3–4°C [e.g., 3.6°C in January 2020, Water Information System, Ministry of Land, Infrastructure, Transport and Tourism (2021b)]. Therefore, although future studies on the conditions related to natural reproduction of *Eleotris oxycephala* (e.g., minimum water temperature) are necessary, *Eleotris oxycephala* is unlikely to mature and reproduce in the Yoneshiro River system. Thus, the juvenile individual collected in this study most likely arrived in the Yoneshiro River system following larval dispersion via the Tsushima Current from the south. Indeed, the Tsushima Current, and its derivatives, are known to facilitate the north-eastward dispersal of other fish species which are mainly distributed in the southern part of Japan [e.g., *Scatophagus argus* (Linnaeus, 1766), Akita Prefecture Agriculture, Forestry and Fisheries Technology Institute, Fisheries Promotion Center (2008); *Naso vlamingii* (Valenciennes, 1835), Nomura et al. (2021); *Arothron hispidus* (Linnaeus, 1758), Shiogaki et al. (2004)]. There is a possibility that the juvenile individual collected in this study dispersed from the species northern limit it on the Pacific Ocean coastline of Honshu [i.e., Fukushima Prefecture, Kuraishi (2014)]. This would have meant dispersing to the Yoneshiro River system in Akita Prefecture via the Kuroshio Current (and its derivatives) and counter currents of the Tsushima Current. However, this route is at least 800 km long, and longer than the Sea of Japan coast dispersal route described above (i.e., from Fukui Prefecture via the Tsushima...
Eleotris oxycephala was first detected along the coast of Honshu, in Tottori Prefecture in 1998 (except for records as an invasive species in Ishikawa Prefecture, Table 1). After 2000, records of *E. oxycephala* have been increasing along the coastline from Shimane to Akita Prefecture (Table 1). Moreover, both juveniles (< 55.0 mm SL) and adult fish (≥ 55.0 mm SL) have been recorded in Fukui, Kyoto, Tottori, and Shimane Prefectures, although only juveniles have been recorded in Akita, Ishikawa, and Hyogo Prefectures (except for records as an invasive species, Table 1). These increases in records of *E. oxycephala*, including adult fish, in recent years might be related to an increase in the number of fish collection surveys occurring in rivers along the Sea of Japan coast of Honshu, making it easier to find *E. oxycephala*. Indeed, Tashiro *et al.* (2017) stated that increased survey effort has contributed to increases in the number of newly recorded fish species in the Sea of Japan in recent years. In addition to an increase in the number of fish collection surveys, rising water temperatures due to global warming could also be a contributing factor. In fact, the seawater temperature in the Sea of Japan around Honshu has risen by about 1.3–1.8°C over the past 100 years (Japan Meteorological Agency, 2021), and it is highly likely that the water temperature in tidal reaches, which are the preferred habitat of *E. oxycephala*, has also risen. The northward range extension of southern fishes, most likely caused by rising water temperatures in the Sea of Japan, has also been observed in other species [*e.g.*, *Hippichthys penicillus* (Cantor, 1849), *Yamaguchi* (2014); *Epinephelus coioides* (Hamilton, 1822), *Kawano* *et al.* (2021); *Redigobius bikolanus* (Herre, 1927), Yamakawa *et al.* (2021)](1). Furthermore, Masuda (2008) described that in Wakasa Bay in the Sea of Japan, southern fishes had increased significantly in the 2000s compared to the 1970s due to rising water temperatures. Increases in water temperature due to global warming are expected to continue (Hasumi, 2017). Therefore, it is important to monitor the northward range extension of southern fishes such as *E. oxycephala*, in terms of biogeography and conservation biology, as well as fisheries.

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Japan. [Translated from Japanese.] (In Japanese.)


Maizuru Citizen Newspaper, 2009. Mr. Kamiyanagi, a fifth grader at Asago Elementary School, caught Eleotris oxycephala in the Yura River: this is the northernmost record in the Sea of Japan side. http://maipress.co.jp/news/area%e6%9c%9d%e6%99%85%e5%b0%8f%e7%a6%8c%95%e5%b9%b4%e5%b4%91%e4%b8%8a%e6%9e%b3%e5%90%b9%e3%80%81%e7%94%b1%e8%89%af%e5%b7%9d%e3%81%7e%32%ab%e3%83%af%e3%82%2a%e3%83%aa%e3%82%b4%e9%87%a3%e3%82%8b-%e6%97%a5.html (accessed on 30 March 2021) [Translated from Japanese.] (In Japanese.)


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