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Impact of long-term habitat loss on the Japanese eel *Anguilla japonica*

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A B S T R A C T

Since the 1970s, the loss of temperate-zone anguillid eels, particularly *Anguilla anguilla*, *Anguilla rostrata*, and *Anguilla japonica*, has exceeded 90% based on estimates of glass eel recruitment. The cause of this decline has not been conclusively determined, although many factors have been proposed. In East Asia, the consequences of long-term habitat loss and deterioration of habitat quality on the sustainability of Japanese eel resources are important. Impacts have already occurred and are expected to increase because hundreds of millions of people live near estuaries and rivers that have undergone, and further, are expected to continue to undergo, substantial changes in land use. Driven by economic growth, these landscape changes have resulted in, and may continue to produce, the large-scale destruction of eel habitats. We used chronological Landsat imagery to measure Japanese eel habitat reduction from human activities in 16 rivers in East Asia, including Japan, Korea, Taiwan, and China. On average, 76.8% of the effective habitat area (*Ae*) was lost in these 16 rivers from the 1970s–2010s. Taiwan and China had the highest percentages of *Ae* loss, with declines of 49.3% and 81.5%, respectively. Extensive habitat loss may play an important role, together with regional climate phenomena such as the ENSO and overfishing, in the decline of the Japanese eel in East Asia. Measures targeting habitat restoration and protection may need to be integrated into management planning for Japanese eel resources in an international rather than regional context.

1. Introduction

The catadromous eel (genus *Anguilla*) is an important aquaculture species in East Asia. The spawning ground of the Japanese eel is west of the Mariana Islands (12–16° N, 142° E) (Tsukamoto, 1992, 2006). The hatched leptocephali drift from their spawning grounds via the North Equatorial Current (NEC), inhabit the Kuroshio for a period of four to six months, and are transported to the coast of Northeast Asia (Cheng and Tzeng, 1996). They then metamorphose into glass eels along the continental shelf and enter estuaries and rivers for subsequent growth (Tesch, 2003; Aoyama, 2009). In recent years, strontium/calcium (Sr/Ca) ratios in otoliths have been used to evaluate likely levels of salinities experienced during the life history of eels (Tzeng et al., 1997; Tsukamoto et al., 1998; Han et al., 2003). The Japanese eel is regarded as a facultative catadromous fish that can grow up in freshwater, estuarine, or coastal environments (Tsukamoto and Arai, 2001; Daverat et al., 2006). Freshwater and estuarine habitats may be the most important during their growth phase (yellow eel), during which they must accumulate energy reserves before silvering to complete their reproductive cycle.

Because of the lack of commercial artificial propagation, eel fry used in aquaculture can only be obtained via the field capture of glass eels in estuaries (Okamura et al., 2013). However, natural stocks of glass eels, including the Japanese eel (*Anguilla japonica*), European eel (*Anguilla Anguilla*), and American eel (*Anguilla rostrata*), have significantly decreased in the last four decades (Dekker, 2004), although some indicators show recent (since 1990) upturns in the abundance of the American eel (DFO, 2014). Prior to the 1970s, annual Japanese glass eel recruitment in the East Asia region was estimated to exceed 1000 metric tons (Han et al., 2012). The average catch of Japanese glass eels in East Asia has since decreased to 20–90 tons, equivalent to <10% of the resource in the 1970s (Han, 2013). There are many factors contributing to the global decline of Japanese eel resources, including both oceanic phenomena (e.g., El Niño–Southern Oscillation [ENSO] events, current speed fluctuations, salinity fronts, and the NEC bifurcation) and land-based impacts (e.g., habitat destruction, pollution, and overfishing) (Kimura et al., 2001; Knights, 2003; Tatsukawa, 2003; Kim et al., 2007; Zenimoto et al., 2009; Tzeng et al., 2012).

Abbreviations: Ae, effective habitat area.

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Although climate-driven impacts such as global warming or ENSO events may be important factors underlying the instability and decline of eel resources (Kimura et al., 2001; Kim et al., 2007; Zenimoto et al., 2009), other impacts such as long-term habitat degradation and loss should not be overlooked, as these impacts can be long-lasting and irreversible. In recent decades, coastal and estuarine habitats of Japanese eels have suffered intense anthropogenic usage, including reclamation, construction of cemented revetments, pollution, invasive species introductions, flow regulation and impoundments, and overexploitation (Cowx, 2002; Allan, 2004; Dudgeon et al., 2006). These anthropogenic pressures threaten the conservation of eels and the sustainability of their fisheries. Unlike pelagic fishes that spend their entire life cycle in the marine environment, the catadromous life histories of eels include both marine (leptocephali, silver eel) and estuary/freshwater (glass eel, elver, and yellow eel) environments (Tesch, 2003; Tsukamoto, 2006). The quality and availability of suitable habitats ultimately determine the sustainability of eels as a fishery resource; therefore, it is important to understand the impacts of long-term habitat loss and degradation, especially in estuaries and freshwater habitats. However, a robust and quantitative assessment of the decline of eel habitats is still lacking.

The consequences of long-term habitat loss and degradation may be particularly severe in East Asia. Hundreds of millions of people currently inhabit areas surrounding estuaries and rivers in Japan, Korea, Taiwan, and China. In recent decades, these countries have experienced or are experiencing rapid economic development, along with large-scaled urbanization and industrialization. Impacts of extensive land use/landscape change (LULC) following economic, industrial, and urban growth in these countries include the substantial loss and deterioration of eel habitats. Many estuarine habitats in this region have been substantially degraded (MacKinnon et al., 2012), while damming and embankment permanently blocks migration routes and eliminates suitable habitats (Feunteun, 2002). It is likely that even if the impacts of global climate change are eventually mitigated, eel resources will not recover to previous levels because of the gradual and long-term loss of suitable habitats. However, this risk has not been quantitatively assessed.

One challenge in quantitatively assessing the extent of long-term habitat decline relates to the lack of historical environmental and habitat baselines. Although glass eels were used in aquaculture prior to the 1970s, the sustainability of eel resources, as well as the availability and suitability of eel habitat, did not receive sufficient attention until the recent and significant decline of glass eel abundance. It is very difficult to quantitatively determine the present habitat size in the absence of prior estimates. In areas where conservation awareness is secondary to rapid economic growth, such as in Taiwan and China, the extent of habitat loss and habitat quality deterioration can be substantial.

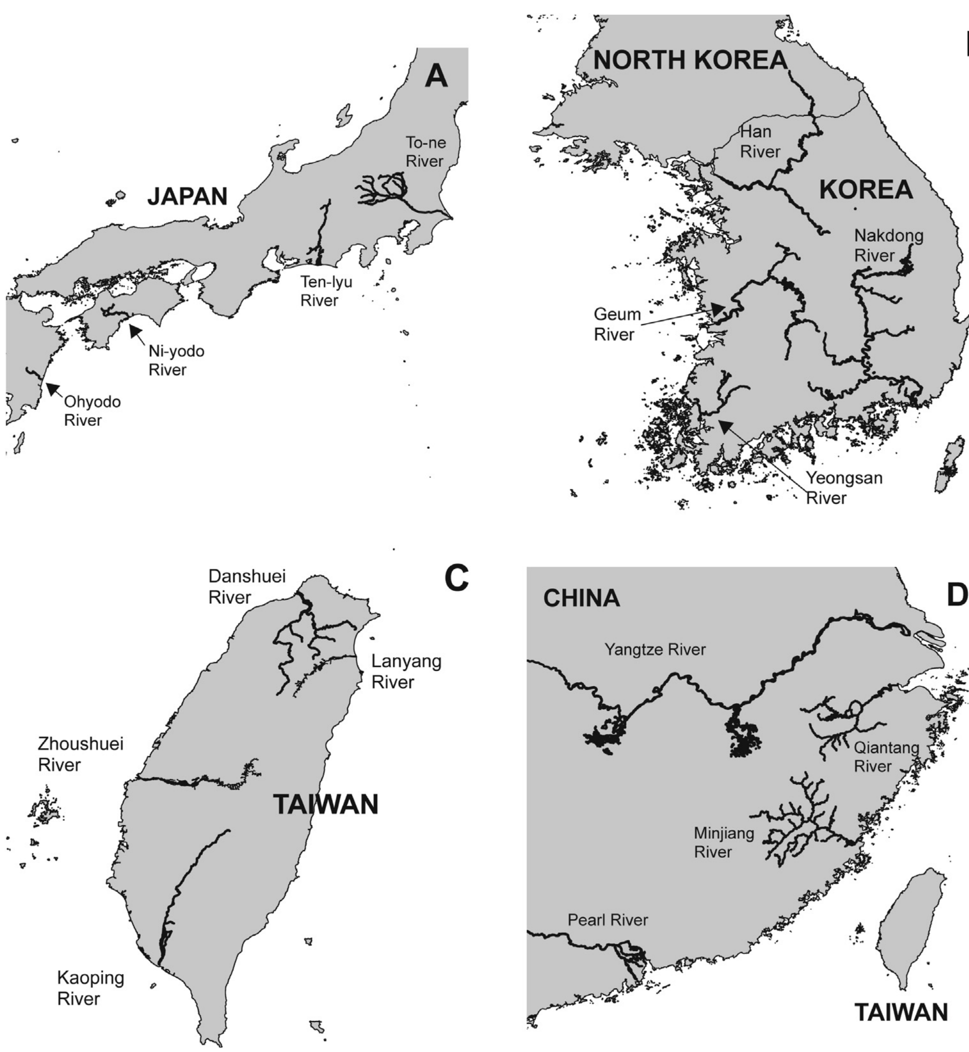

Fig. 1. Locations of the major rivers studied in (a) Japan, (b) Korea, (c) Taiwan, and (d) China.