

## Research Article

## Replacement of nonnative rainbow trout by nonnative brown trout in the Chitose River system, Hokkaido, northern Japan

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### Abstract

In this study, evidence for interspecific interaction was provided by comparing distribution patterns of nonnative rainbow trout *Oncorhynchus mykiss* and brown trout *Salmo trutta* between the past and present in the Chitose River system, Hokkaido, northern Japan. *O. mykiss* was first introduced in 1920 in the Chitose River system and has since successfully established a population. Subsequently, another nonnative salmonid species, *S. trutta* have expanded the Chitose River system since the early 1980s. At present, *S. trutta* have replaced *O. mykiss* in the majority of the Chitose River, although *O. mykiss* have persisted in areas above migration barriers that prevent *S. trutta* expansion. In conclusion, the results of this study highlight the role of interspecific interactions between sympatric nonnative species on the establishment and persistence of populations of nonnative species.

**Key words:** biological invasions, interspecific interaction, migration barrier, nonnative salmonids

### Introduction

Interspecific interactions between nonnative and native species play a key role in the decline of native species populations and the collapse of native ecosystems (Parker et al. 1999) and also the establishment and/or persistence of nonnative species (Southward et al. 1998; Melbourne et al. 2007). Since multiple nonnative species co-occur in many regions, interspecific interactions between nonnative species may also influence nonnative species (Ricciardi and MacIsaac 2011). For example, the invasional meltdown hypothesis, which proposes that nonnative species facilitate successful establishment of other nonnative species, is a commonly accepted theory among ecologists (Simberloff and Von Holle 1999). Moreover, species replacement is also likely to occur between the interacting nonnative species; this process has not been well evaluated to date.

A number of salmonid species have been introduced into many nonindigenous regions, and

have had devastating effects on native species (Fausch 1988; Townsend 1996). One of the most serious problems of the devastating effects is species replacement of native salmonids by nonnative salmonids (Fausch 1988). Several kind of interspecific interactions have been proposed as potential mechanisms of replacement such as competition, predation, hybridization and introduction of parasites and disease (Krueger and May 1991). Moreover, multiple nonnative salmonids co-occur in many regions (e.g. Houde et al. 2014; Kitano et al. 2014). Species replacement is also likely to occur between nonnative salmonid species, if they interact with one another. That is to say, interspecific interactions are closely related to the establishment and persistence of populations of each nonnative salmonid species.

In Hokkaido, northern Japan, nonnative rainbow trout, *Oncorhynchus mykiss* (Walbaum, 1792), and brown trout, *Salmo trutta* (Linnaeus, 1758), co-occur in some regions (Takami and Aoyama 1999). Both *O. mykiss* and *S. trutta* are listed

among 100 of the world's worst invasive alien species by IUCN, and effective management strategies are urgently needed for the purpose of aquatic ecosystem conservation (Lowe et al. 2000). Previous studies have noted that both species have successfully established populations in stable flow streams such as spring-fed streams (Fausch et al. 2001; Inoue et al. 2009; Kawai et al. 2013). In these streams, *O. mykiss* and *S. trutta* are likely to successfully establish by competitive exclusion of white-spotted charr, *Salvelinus leucomaenis* (Pallas, 1814), a common native salmonid species (Morita et al. 2004; Hasegawa and Maekawa 2009). Conversely, habitat and/or food niche segregation between both nonnative salmonid species and native masu salmon, *Oncorhynchus masou* (Brevoort, 1856), another common native salmonid species, may also facilitate successful establishment of nonnative salmonid species (Hasegawa and Maekawa 2006; Inoue et al. 2009; Hasegawa et al. 2010; Hasegawa et al. 2012a). Interestingly though, the nature of interactions between *O. mykiss* and *S. trutta* have not yet been evaluated.

This study documents the species replacement of nonnative *O. mykiss* by nonnative *S. trutta* in the Chitose River system, southwestern Hokkaido between the 1990s and 2010s, then discusses how interspecific interactions may influence their population establishment and/or persistence.

## Methods

### Study area

The Chitose River system is located in southwestern Hokkaido, northern Japan (Figure 1). The river has several unpassable dams for fishes (Figure 1). Underground flow isolates a part of Mamachi stream (around reaches 13–15) (Figure 1). Since the 1970s, the BOD (biochemical oxygen demand) values have been almost lower than 2.5 mg/L in the study area (Ishikawa et al. 2013). Thus, water quality has been well enough for inhabiting salmonid species. Nonnative *O. mykiss* had been introduced into the system from 1927 to 1955 as a result of national policy (Bureau of Fishery, Ministry of Agriculture and Forestry of Japan 1927; Yoshizumi 2005). And also, a fish hatchery beside a main stem of the Chitose River (nearby study reach “p” in Figure 1a) had kept *O. mykiss* until 1985 and some individuals might have escaped from the hatchery to the river (Yoshimizu 2005; Nogawa pers.

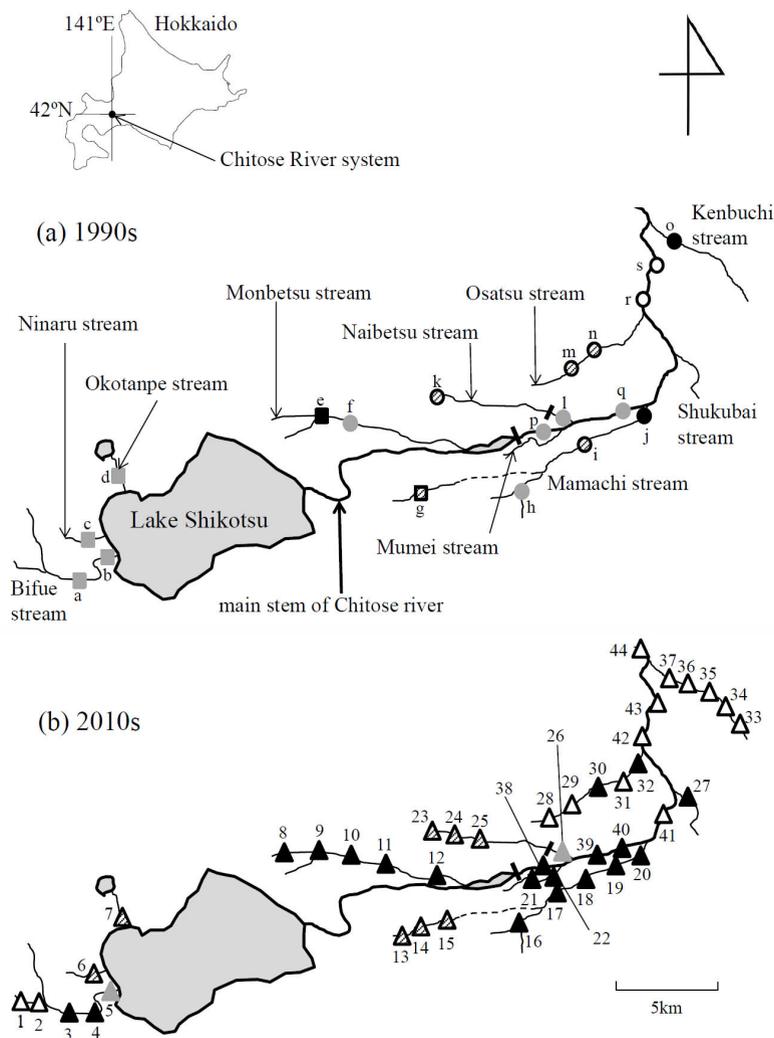
comm.). As a result, a self-sustaining population was confirmed in the early 1980s (Urawa 1989). Subsequently, nonnative *S. trutta* were first recorded in 1984 (Urawa 1989) and are now widely distributed in the system (Kawai et al. 2013). Personal transportation for recreational fishing is considered a major cause of *S. trutta* introduction (Takami and Aoyama 1999). However, the introduction of *S. trutta* has been legally prohibited for a decade (Shimoda 2012).

### Fish distribution

The distribution of fish in the 1990s was determined from existing literature (reaches e–s: Chitose City and Research Institute of Takugin 1997; reaches a–d: Takayama et al. 2002). In these studies, some study reaches were not recorded in detail. For example, locations were recorded at the spatial level of “tributary” only (square symbols in Figure 1a). Fish sampling was conducted using minnow traps, dip nets, and electrofishing unit. The presence or absence of a species was recorded in all studies.

The distribution of fish in the 2010s was surveyed in 44 reaches. Two pass electrofishing (Smith-Root Inc., Vancouver, WA, USA) was conducted in the tributaries of Chitose River and the inlets of Lake Shikotsu (length 50–150 m). In the main stem of Chitose River, electrofishing was conducted along the river bank for 25 to 45 min (reaches 38–44). Thirty-five reaches (reaches 1–5, 8–12, 16–22, 27–44) were surveyed from the end of May to the beginning of June 2011 (datasets on *S. trutta* and study reach environments were converted from Kawai et al. 2013). Seven reaches (reaches 13–15, 23–26) were surveyed in the summer of 2013. The number of individuals captured for each species was recorded. All *S. trutta* and *O. mykiss* individuals were anesthetized using ethyl 3-aminobenzoate methanesulfonic acid, and measured to the nearest 1 mm (fork length). Then, young-of-the-year and the older individuals were distinguished. In this study, we regarded that *S. trutta* and *O. mykiss* smaller than 50 mm and 60mm were young-of-the-year with certainty, respectively. Young-of-the-year individuals represent evidence of successful establishment of a population (Kolar and Lodge 2001; Kawai et al. 2013)

In two reaches (reaches 6 and 7), a fish survey was conducted by underwater observation in the beginning of October 2013. An observer (KH) entered the stream during daytime at the lower end of each site and crawled slowly upstream in



**Figure 1.** Distribution of *Onchorhynchus mykiss* and *Salmo trutta* in the Chitose River system in the (a) 1990s (circles and squares) and (b) 2010s (triangles). Locations of major dams are marked by short black bars, and underground flow is represented by the dashed line. (a) The study reaches for which the location is correctly identified are represented by circles, whereas those that could not be located accurately are represented by squares. Slashed symbols: *O. mykiss* only; Black symbols: *S. trutta* only; Grey symbols: both *O. mykiss* and *S. trutta*; White symbols: no *O. mykiss* or *S. trutta* were recorded.

a zigzag pattern (Thurow 1994). The number of individuals observed was recorded for each species.

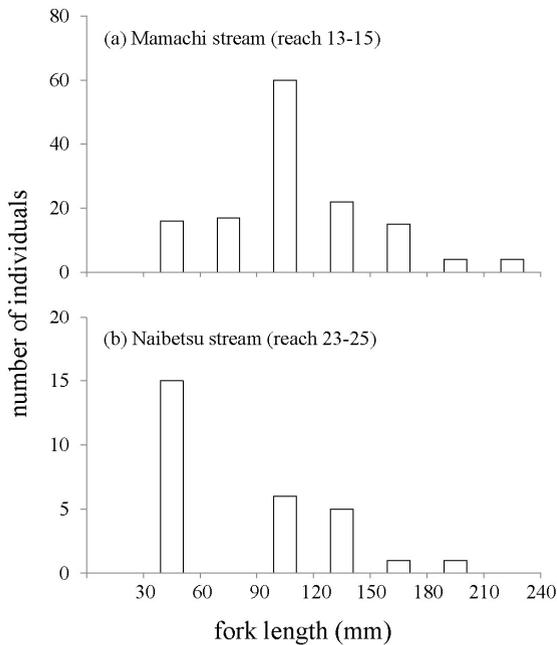
Plots of each study reach were color-coded to distinguish four patterns of fish distribution, i.e. *O. mykiss* and *S. trutta* were sympatric, *O. mykiss* or *S. trutta* were allopatric, and *O. mykiss* and *S. trutta* were absence (Figure 1). Then, we visually compared distribution patterns of *O. mykiss* and *S. trutta* between 1990s and 2010s, and evaluated the change of distribution patterns of the two species.

## Results

Both *O. mykiss* and *S. trutta* were widely distributed in the Chitose River system in the 1990s (Figure 1a). The two species were found sympatrically in nine reaches (grey symbols in Figure 1a). In study reach a–d, *O. mykiss* was dominant in abundance (Table 1). *O. mykiss* and *S. trutta* were found individually in five (slashed symbols) and three (black symbols) reaches, respectively (Figure 1a).

**Table 1.** Number and proportion of *Onchorhynchus mykiss* and *Salmo trutta* in study reach a-d in 1990s. Data sets were originally shown in Takayama et al. (2002).

reach	a	b	c	d
<i>O. mykiss</i>	239 (63%)	273 (62%)	283 (99%)	30 (79%)
<i>S. trutta</i>	142 (37%)	169 (38%)	3 (1%)	8 (21%)

**Figure 2.** Body size composition of *Onchorhynchus mykiss* captured in (a) Mamachi stream (reaches 13–15) and (b) Naibetsu stream (reaches 23–25).

In the 2010s, *S. trutta* was still widely distributed in the Chitose River system (Figure 1b). Conversely, the distribution of *O. mykiss* was mostly restricted to the area above the migration barriers (reaches 13–15, 23–25) (Figure 1b). Young-of-the-year *O. mykiss* were captured in these areas (Figure 2). Although *O. mykiss* were found together with *S. trutta* in two reaches (grey symbols in Figure 1b), the percentages of *O. mykiss* were only 2.9% (3 individuals) (reach 5) and 1.3% (1 individual) (reach 26) (see supplementary material Table 1S for details). In Ninaru stream (reach 6) and Okotanpe stream (reach 7), only *O. mykiss* were observed by underwater observation.

## Discussion

In the Chitose River system, nonnative *O. mykiss* were widely distributed, and greatly exceeded *S. trutta* in abundance until the 1990s (Urawa 1989; Chitose City and Research Institute of Takugin 1997; Takayama et al. 2002). However, the current study documented a dramatic decline of nonnative *O. mykiss* from the 1990s to the 2010s, and the widespread distribution of *S. trutta* in the 2010s in the river system. Thus, species replacement of nonnative *O. mykiss* by nonnative *S. trutta* has likely occurred. The end of cultivation in early 1980s (and also stocking) may cause the decline of *O. mykiss* (Yoshimizu 2005; Nogawa *personal communication*). Our results cannot rule out the possibility that *S. trutta* successfully expanded using niches occupied by *O. mykiss*. Additionally, interspecific interactions between *O. mykiss* and *S. trutta* must be considered to understand the mechanism of the species replacement.

Although piscivory by nonnative *S. trutta* represents a potential mechanism to explain the decline in *O. mykiss* distribution (Lowe et al. 2000), Hasegawa et al. (2012b) concluded that fish were not primary prey of *S. trutta* in the Chitose River system. Instead, Blanchet et al. (2007) suggest that there is intense interspecific competition between *O. mykiss* and *S. trutta* due to large niche overlap in an artificial channel. In the case of the Chitose River system, therefore, interspecific competition may have facilitated species replacement of *O. mykiss* by *S. trutta*.

The early stages of their life history may play a key role in our understanding of the nature of interspecific interactions. Fausch (2007) noted that recruitment of *O. mykiss* fry was hampered by competition from *S. trutta* fry, which emerge earlier than *O. mykiss*, and can therefore occupy the preferred feeding habitat. However, there appear to be conflicting outcomes from their interactions. For example, Scott and Irvine (2000) suggested that superimposition of spring spawning *O. mykiss* on the redds of *S. trutta* (spawn in late autumn to winter) caused elimination

of the *S. trutta* population by damaging eggs of *S. trutta* due to disturbance of spawning gravels. In the Chitose River system, the former hypothesis is likely to be more suitable for explaining the observed results. However, there is a clear need for further studies on the egg to fry stages of both species, in order to confirm this hypothesis.

The results of the survey in the 2010s from reaches 13–15 (Mamachi stream) and 23–25 (Naibetsu stream), where *O. mykiss* remained the sole inhabitants and their reproduction were documented, suggest that *O. mykiss* populations have been able to persist in areas where *S. trutta* were unable to expand because of migration barriers. Fausch et al. (2009) have noted that increasing habitat connectivity can foster the wide-spread successful establishment of nonnative species, a major threat to native species persistence. Nonnative species that have negative effect on another nonnative species may also suffer the same risk associated with connectivity. These results also support our hypothesis that interspecific interaction likely caused the species replacement of *O. mykiss* by *S. trutta*.

*O. mykiss* also remained allopatrically in Ninaru (reach 6) and Okotanpe stream (reach 7), which are inlets of Lake Shikotsu. In these streams, *S. trutta* were also rare in 1990s in spite of no migration barriers. Thus, the stream morphology may be unsuitable for *S. trutta* rearing or spawning.

In conclusion, the results of this study suggest that interspecific interactions have a significant influence on population persistence and/or establishment of nonnative species. In this study, evidence for interspecific interaction and perhaps exclusion was provided by comparing distribution patterns of nonnative *O. mykiss* and *S. trutta* between the past and present. To elucidate the mechanism of the species replacement, further studies focusing on interspecific interactions, for example, experiments evaluating the effect of interspecific competition (Fausch 1998) are required. Although water quality has been sufficient for inhabiting salmonid species in the study area (Ishikawa et al. 2013), other man-made changes within stream environments such as loss of pool-riffle sequences due to channel alteration may influence the outcome of interspecific interactions (Dunson and Travis 1991) and/or habitat use of each species (Chen et al. 2014). It is likely that these additional changes are also likely to influence the distribution patterns of the two nonnative salmonids in the Chitose River system.

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## Supplementary material

The following supplementary material is available for this article.

**Table 1S.** Total number of fish captured (observed) for each fish species in each study reach.

This material is available as part of online article from:

[http://www.aquaticinvasions.net/2014/Supplements/AI\\_2014\\_Hasegawa\\_et\\_al\\_Supplement.xls](http://www.aquaticinvasions.net/2014/Supplements/AI_2014_Hasegawa_et_al_Supplement.xls)