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Evaluation of the Predatory Effects of an Introduced Fish, *Culter alburnus*, on the Fish Community in a Small Stream of Northern Taiwan

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Yuh-Wen Chiu, Cheng-Wei Tso, Bao-Sen Shieh, Chi-Chang Liu, Yao-Sung Lin, and Shih-Hsiung Liang (2012) Evaluation of the predatory effects of an introduced fish, *Culter alburnus*, on the fish community in a small stream of northern Taiwan. *Zoological Studies* **51**(8): 1438-1445. *Culter alburnus* is an indigenous carnivorous fish which was originally distributed in central Taiwan, but was introduced into Feitsui Reservoir and its surrounding streams of northern Taiwan after 2000. From Apr. 2008 to May 2009, 14 monthly samples were collected in Jingualiao Stream by angling from 4 sampling sites: 2 sites were located above a check dam without *Cul. alburnus*, and 2 other sites were located below the dam where *Cul. alburnus* was present, having migrated upstream from the Feitsui Reservoir. The aim of this study was to evaluate the predation impacts of *Cul. alburnus* by comparing the compositions, abundances, and size-frequency distributions of fish communities above and below the check dam. In total, 2791 individuals of 18 fish species were collected, including 275 *Cul. alburnus* caught below the dam. A diet analysis showed that 11 of 30 *Cul. alburnus* (33.3%) had consumed a total of 26 fish, 23 of which were *Candidia barbata*. The abundance of *Can. barbata* was significantly greater above the dam. Additionally, the body size of *Can. barbata* collected above the dam averaged < 12.9 cm, whereas the body size of individuals below the dam averaged > 11 cm. We concluded that predation by the introduced *Cul. alburnus* resulted in a decrease in the total abundance and a change in the age structure of populations of native fish species, such as *Can. barbata*, that occupy mid- and surface waters. It is possible that predation by the introduced *Cul. alburnus* may also generate a trophic cascade effect on the animal communities in lotic waters. To conserve the freshwater biodiversity in Taiwan, we suggest that greater attention be given to the introduction of indigenous fish species by administrative agencies and the general public to prevent invasions by exotic species. http://zoolstud.sinica.edu.tw/Journals/51.8/1438.pdf

Key words: Predation, Fish Introduction, *Culter alburnus*, *Candidia barbata*, Taiwan.

Invasive species have become major threats to native biodiversity globally (Vitousek et al. 1996). Simberloff (1981) indicated that of all invasive animals, predatory species may cause the most intense impacts on species compositions and structures of native communities. Severe impacts, such as species extinction, may be generated by invasive predators because they are situated at the top of the food chain (Townsend 1996). Such impacts are commonly reported as a result of the introduction of predators to isolated islands or lakes (Primack 1993). Examples include the decline and disappearance of endemic birds, mammals, lizards, and frogs caused by the brown tree snake (*Boiga irregularis*) in Guam (Rodda et al. 1997) and the loss of cichlid species due to Nile

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*To whom correspondence and reprint requests should be addressed. Tel: 886-7-7172930 ext. 7310. Fax: 886-7- 6051365. E-mail:shliang@nknucc.nknu.edu.tw perch (*Lates niloticus*) in Lake Victoria (Witte et al. 1992). However, those studies considered the impacts caused by exotic predatory species, and few studies assessing the effects generated by the introduction of indigenous predatory species have been reported.

In Taiwan, introductions of indigenous fish species by anglers are commonly documented (Ma et al. 2006). *Culter alburnus* naturally occurs in Sun Moon Lake, central Taiwan, and was frequently introduced into reservoirs, ponds, and streams on the west coast of Taiwan (Chang 2003). *Culter alburnus* is a predatory species of the mid- and upper water zones of lentic waters (Chen 2009). The diet of *Cul. alburnus* includes early developmental stages of aquatic invertebrates when it is younger and has a smaller body size, and then it begins to prey mainly on fish after its body length exceeds 150 mm (Liu 2008). After its introduction into the Feitsui Reservoir, northern Taiwan, in 2000, the abundance of *Cul. alburnus* in the reservoir increased, and expanded its distribution into surrounding streams after 2002 (Chang 2003). By 2007, *Cul. alburnus* had become the 2nd most abundant fish species in the Feitsui Reservoir (Wang 2007).

A check dam was built on Jingualiao Stream, a tributary that flows into the Beishih River just before the latter stream enters the reservoir, to reduce sedimentation in the reservoir, but it now also blocks the upstream migration of *Cul. alburnus* (Fig. 1). An experimental stream section was established to evaluate the predatory effects of *Cul. alburnus* on the local fish community. The aim of this study was to assess the predation effects of *Cul. alburnus* on the fish community by comparing the compositions, abundances, and size structures of fish communities above and below the check dam.

MATERIALS AND METHODS

The study was conducted in Jingualiao Stream, a subtropical tributary that enters the Beishih River before it flows into the Feitsui Reservoir. This stream's length is approximately 16 km, and its elevation ranges 160-620 m. The annual rainfall within the stream's drainage area is approximately 2500 mm. The headwaters of the stream are still in a natural state with the exception of a few concrete stream banks in regions with human populations, whereas many downstream sections have been disturbed by channelization, the construction of concrete banks, agriculture, and recreational activities. To reduce sediment accumulation, a check dam was built approximately 2.2 km above the site where the tributary flows into the Beishih River (Fig. 1).

Four sampling sites were chosen: 2 sites above the check dam (sites A and B) and 2 sites below the check dam (sites C and D) (Fig. 1). Site A was 560 m above the dam, and site B was the pool region immediately upstream of the dam. Site C was 920 m below the dam, and site D was 1620 m below the dam. At each sampling site, a pool region 20 m long, 10 m wide, and > 30 cm deep was selected because *Cul. alburnus* prefers a lentic habitat.

From Apr. 2008 to May 2009, 4 water quality variables, including water temperature, pH, dissolved oxygen (DO), and conductivity, were measured monthly at each site. Water temperature, pH, and conductivity were recorded using a pH/conductivity meter (ExStik EC 500), and DO was monitored with a DO meter (ExStik DO600).

During the study period, 14 fish samples were collected monthly from each sampling site. To collect fish specimens, 3 angling methods, including float, fly, and lure fishing, were applied at each site by 6 anglers, with 2 anglers using each method for 40 min. The float and fly fishing methods were used to capture smaller fishes, of the *Zacco* and *Candidia* genera, and lure fishing was mainly used to capture *Cul. alburnus*. During each sampling period, 2 plastic fish traps were also placed overnight for at least 12 h in each stream section to catch benthic species. Species identification, total length, body weight, and abundance of fish samples caught by the different methods were separately recorded.

To prevent the removal of too many individuals from the study population, we decided to sacrifice only 1/5 of the total catch of *Cul. alburnus* for the diet analysis, and the rest of the catch was released back to the sampled habitats after taking measurements. In total, 30 specimens with body sizes ranging 30-40 cm were used to document the diet contents of *Cul. alburnus*. Over the study period, at least 2 individuals were dissected each month for the diet analysis except in Nov. 2008. Stomach contents of dissected individuals were collected, washed in distilled water, and preserved in 75% alcohol for species identification and morphometric measurements.

In this study, 2 prey fishes, *Candidia barbata* and *Zacco pachycephalus*, were identified. Among them, *Can. barbata* was identified by a dark vertical stripe (Fig. 2), while the only *Z. pachycephalus* was recognized by > 10 dark, lateral bands across its body.

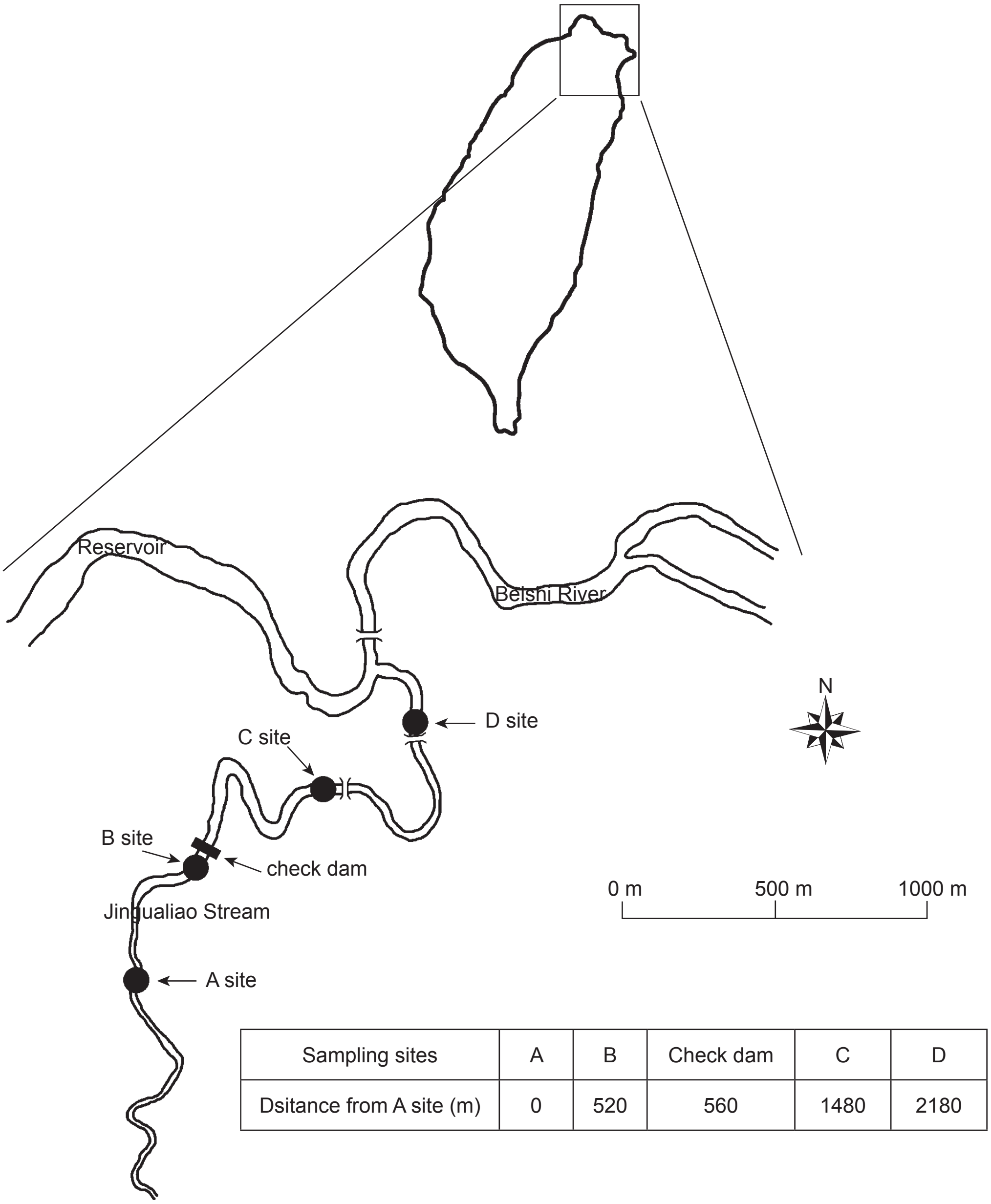
Statistical analysis

Numerical abundances of fish species were compared among sites with an analysis of variance (ANOVA) and Duncan's multiple-range comparison test. The impacts of *Cul. alburnus* on the size-frequency distributions of fishes above and below the dam were assessed with a Chi-squared test.

RESULTS

Environmental characteristics

Physiochemical measurements among all 4 sites were similar. No significant differences in the 4 environmental variables analyzed (ANOVA, $p > 0.05$) were found among the sites. During the study period, the mean water temperature



Sampling sites	A	B	Check dam	C	D
Dsitance from A site (m)	0	520	560	1480	2180

Fig. 1. Sampling locations in the main stream and tributaries of the Jingualiao Stream, Taiwan.

varied 20.0-21.7°C, and the mean pH ranged 7.3-7.5. The DO content ranged 6.9-7.2 ppm, and the mean conductivity varied 89.4-91.4 μs/cm.

Fish density

In total, 18 fish species and 2791 individuals were collected from the 4 sampling sites (Table 1). These samples included 1279 *Candidia barbata* (45.8%), the most abundant species except at site D. Abundances of *Can. barbata* significantly varied among sites (ANOVA, $F_{3,39} = 24.1$, $p < 0.01$) (Table 2). Abundances of *Can. barbata* at the 2 sites above the dam did not significantly differ. Similarly, abundances of *Can. barbata* at the 2 sites below the dam did not significantly differ.

Fig. 2. Preyed *Can. barbata* collected from the stomach of *C. alburnus* in Jingualiao Stream, Taiwan.

A significant difference in abundances among sites was also found for *Acrossocheilus paradoxus*, the 2nd most dominant species (ANOVA, $F_{3,39} = 3.28$, $p < 0.01$) (Table 3). Despite greater numbers of *A. paradoxus* being collected from sites above the dam than from sites below the dam, the statistical difference between the 2 sites above and below the dam was both not significant.

In this study, 275 individuals of *Culter alburnus* were collected, all below the dam (Table 1). Abundances of *Sinibrama macrops* increased from upstream to downstream (Table 1), while for other fish species that occurred on both sides of the dam, more individuals were generally found above the dam than below the dam.

Diet analysis

In total, 30 *Cul. alburnus* were dissected to examine the diet contents (Table 4). Among them, 11 *Cul. alburnus* (33.3%) contained 26 prey fishes.

Table 1. Numerical and proportional abundances of all fishes collected at 4 sampling sites based on 14 monthly collections from Apr. 2008 to May 2009

Species	Abundance (%)			
	Above the dam		Below the dam	
	Site A	Site B	Site C	Site D
Candidia barbata	436 (50.3)	630 (66.2)	157 (31.3)	56 (11.9)
Acrossocheilus paradoxus	305 (35.2)	198 (20.8)	111 (22.2)	69 (14.6)
Culter alburnus	0	0	94 (18.8)	181 (38.4)
Sinibrama macrops	3 (0.3)	18 (1.9)	90 (18.0)	125 (26.5)
Zacco pachycephalus	53 (6.1)	48 (5.0)	19 (3.8)	12 (2.5)
Zacco platypus	40 (4.6)	32 (3.4)	10 (2.0)	11 (2.3)
Varicorhinus barbatulus	21 (2.4)	17 (1.8)	8 (1.6)	3 (0.6)
Rhinogobius spp.	4 (0.5)	2 (0.2)	5 (1.0)	2 (0.4)
Hemibarbus labeo	0	3 (0.3)	2 (0.4)	4 (0.8)
Cyprinus carpio	5 (0.6)	4 (0.4)	0	0
Distoechodon tumirostris	0	0	0	3 (0.6)
Microphysogobio brevirostris	0	0	3 (0.6)	0
Ctenopharyngodon idellus	0	0	1 (0.2)	1 (0.2)
Oreochromis spp.	0	0	0	2 (0.4)
Cobitis sinensis	0	0	0	1 (0.2)
Parasilurus asotus	0	0	1 (0.2)	0
Pseudobagrus adiposalis	0	0	0	1 (0.2)
Total	867	952	501	471

Table 2. Numerical abundances of monthly collections of *Can. barbata* at 4 sampling sites in Jingualiao Stream from Apr. 2008 to May 2009. Sites marked with the same letter above the means do not significantly differ based on Duncan's multiple-comparison range test

Year/month	Above the dam		Below the dam	
	Site A	Site B	Site C	Site D
2008				
Apr.	79	63	3	0
May	51	93	7	0
June	13	59	12	0
July	55	52	6	0
Aug.	29	44	1	17
Sept.	29	22	16	1
Oct.	16	35	17	0
Nov.	17	25	14	18
Dec.	20	34	11	4
2009				
Jan.	27	33	31	1
Feb.	26	42	22	8
Mar.	14	28	7	7
Apr.	28	44	7	0
May	32	56	3	0
Total	436	630	157	56
Mean ± standard error	31.1 ± 18.6^{a}	45.0 ± 18.8^{a}	11.2 ± 8.3^{b}	4.0 ± 6.3^{b}

Table 3. Numerical abundances of monthly collections of *A. paradoxus* at 4 sampling sites in Jingualiao Stream from Apr. 2008 to May 2009. Sites marked with the same letter above the means do not significantly differ based on Duncan's multiple-comparison range test

Year/month	Above the dam		Below the dam	
	Site A	Site B	Site C	Site D
2008	9	4	5	6
Apr.				
May	11	1	5	1
June	26	0	5	1
July	18	13	11	9
Aug.	14	7	5	8
Sept.	17	2	0	5
Oct.	15	3	13	0
Nov.	22	20	12	12
Dec.	39	36	15	10
2009				
Jan.	10	7	2	2
Feb.	34	64	15	8
Mar.	41	19	8	1
Apr.	18	15	8	4
May	31	7	3	2
Total	305	198	107	69
Mean ± standard error	21.8 ± 10.7^{a}	14.1 ± 17.4^{ab}	7.6 ± 4.9^{bc}	4.9 ± 3.9^{c}

These prey fishes included 23 *Can. barbata*, 1 *Z. pachycephalus*, and 2 undetermined individuals (Table 4). Among the 23 *Can. barbata*, 17 young (73.9%), 3 subadults (13.0%), and 3 adults (13.0%) were distinguished by the body length distribution.

Body length distributions of *Can. barbata* above and below the dam

Standard lengths of collected *Can. barbata* ranged 2.1-19.8 cm, and 8 size categories were classified using 1.9 cm as the dividing interval. Abundances of *Can. barbata* in the 8 size categories did not significantly differ between the 2 sites above the dam, and a similar result was found for the 2 sites below the dam. Thus, data for 2 sites above and for the 2 sites below the dam were combined and compared to evaluate differences between the length distributions of *Can. barbata* above and below the dam.

For the combined data, proportional abundances of size categories of *Can. barbata* above and below the dam differed (Fig. 3). Above the dam, most of the *C. barbata* collected were in the 1st 5 size categories, generally measuring < 12.9 cm. In contrast, most individuals below the dam had body sizes of > 11 cm. Body length distributions of *Can. barbata* above and below the dam significantly differed (Chi-squared = 111.8, $p < 0.01$).

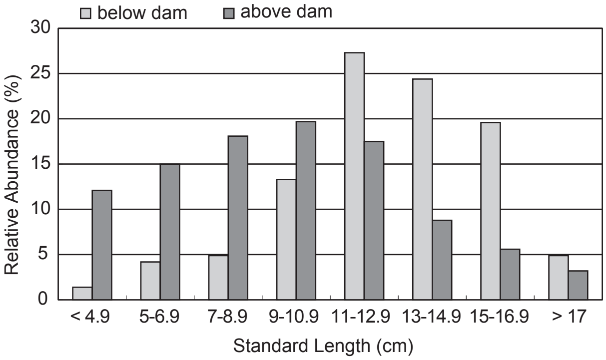


Fig. 3. Proportional abundance of collected *Can. barbata* in 8 standard size classes from sampling sites above and below the dam. Standard size classes are divided into 2-cm intervals.

Similar data treatment and analysis were performed for *A. paradoxus*. However, this analysis found no differences between body length distributions of *A. paradoxus* above and below the dam.

DISCUSSION

Adaptation time for *Culter alburnus*

Several fish surveys were conducted in the same region after 2000 when *Culter alburnus* was introduced into the study region (Chang 2003). In 2002-2003, Chang (2003) recorded only 5 *Cul. alburnus* out of 797 fish collected (0.62%) by electrofishing in a 1-yr study. Wang (2007) used gill nets to catch 930 fish, including 14 *Cul. alburnus* (1.5%), from the Feitsui Reservoir and surrounding streams from June 2006 to May 2007. In this study, 94 and 181 *Cul. alburnus* were separately collected from 2 sites (C and D) below the dam. Moreover, at the lowest (D) site, *Cul. alburnus* replaced *Candidia barbata* as the most dominant species within the community (38.4%). *Culter alburnus* is an indigenous carnivorous fish originally distributed in lentic waters of central Taiwan. Given that an increase in the numerical abundance may reflect environmental adaptation, this indicates that *Cul. alburnus* may still require a period of time for adaptation, as occurred from 2000 to 2009 after its introduction to a lotic habitat

Table 4. Prey fish species and individuals found in 11 *C. alburnus* stomachs from fish collected at 2 sampling sites below the dam. *Can. barbata* specimens were categorized into different life stages based on their body lengths (Yen 1993)

	Can. barbata - Life stage (total length)			*Zacco pachycephalus*	Unidentified
	Young (3-5.9 cm)	Subadult (6-6.9 cm)	Adult (> 7 cm)		
Site C	13	2	0	1	1
Site D	4	1	3	0	1
Total (%)	17 (65.4)	3 (11.5)	3 (11.5)	1 (3.9)	2 (8.0)

in northern Taiwan, as observed in this study.

Predation impacts of *Cul. alburnus*

Water quality parameters of the sampling sites above and below the dam did not significantly vary during the study period. These observations imply that environmental factors might not be the major reason for population declines of many fishes at sites C and D.

Culter alburnus may prey mainly on mid-water and surface fishes. The mouth opening of *Cul. alburnus* is in a very high frontal position (Chen 2009). In this study, the diet analysis of larger *Cul. alburnus* (mainly with body lengths of 30-40 cm) primarily revealed the presence of *Can. barbata* and 1 *Z. pachycephalus*, both of which actively use mid- and surface waters (Chen 2009). Liu (2008) analyzed the diet composition of *Erythroculter ilishaeformis*, a species closely related to *Cul. alburnus*, in Lake Taihu, Wuxi, China. In Liu's (2008) study, *E. ilishaeformis* primarily preyed on *Coilia ectenes taihuensis* and *Hyporhamphus intermedius*, which are both species of mid- and upper waters. Based on those observations, when *Cul. alburnus* is introduced into new habitats, its predacious behavior will generate significant pressure on fish species occupying mid- and surface waters. As few benthic species were collected in this study, determining the predation impacts of this species on benthic species requires further investigations.

Based on the diet analysis, larger *Cul. alburnus* fed primarily on *Can. barbata*. The significantly lower abundances of *Can. barbata* below the dam during the sampling period can at least partially be attributed to predation by *Cul. alburnus*. Thus, predation by *Cul. alburnus* may have significantly decreased the population size of *Can. barbata*. In addition, predation may have modified the body size distribution of *Can. barbata* through selective consumption of younger individuals. In the absence of predation by *Cul. alburnus*, young *Can. barbata* dominated the population above the dam. In contrast, in the presence of *Cul. alburnus*, larger *Can. barbata* dominated the population below the dam. Diet contents of *Cul. alburnus* showed that this species preyed on adult *Can. barbata* and also effectively fed on young individuals with body lengths of 3-5.9 cm (17 of 26, 65.4%) (Table 4). Moreover, despite the existence of climate variations between southern and northern Taiwan, Fang (1996) reported that young *Can. barbata* were present year round in the Nanjishan River of southern Taiwan. In this study, monthly catches at the 2 sites above the dam remained mostly within 42-73 (in 10 of 14 mo, 71.4%), while collections at the 2 sites below dam were also commonly < 20 (in 11 of 14 mo, 78.6%). Judging from monthly collection records, the observed numerical differences in the body size distribution between above and below the dam for *Can. barbata* might not have contributed to the sudden burst of younger individuals.

If this situation persists below the dam, it is possible that the population of *Can. barbata* may be eliminated from this habitat by *Cul. alburnus* through predation on both adult and young fish. Moreover, after the abundance of *Can. barbata* is greatly reduced, it is highly possible that predation pressure of *Cul. alburnus* will switch to other mid- and upper-water species, because *Cul. alburnus* also feeds on other fish species, such as *Z. pachycephalus*.

It is also possible that predation by *Cul. alburnus* will produce a trophic cascade effect on the animal communities of ecosystems where this species has been introduced. This effect may have 2 bases. First, although larger *Cul. alburnus* (with body lengths of 30-40 cm) mainly fed on fish in this study, the food composition of adult *Cul. alburnus* includes small fish and crustaceans, and the diet of smaller *Cul. alburnus* includes plankton, shrimp, and invertebrates as documented in Taiwan (Chen and Fang 1999). Shrimp were also found in the diet of > 20% of *E. ilishaeformis* examined in Lake Taihu (Liu 2008). Second, a trophic cascade effect may also indirectly be generated because *Cul. alburnus* preys heavily on *Can. barbata*, an omnivorous fish in Taiwan that primarily feeds on aquatic invertebrates and benthic algae (Chen and Fang 1999, Chen 2009). Studies of farm ponds in Japan showed that a trophic cascade based on top-down control occurred in the presence of exotic predators, such as largemouth bass (*Micropterus salmoides*) and bluegill (*Lepomis macrochirus*). The trophic cascade effect would directly decrease the numbers and body sizes of fish, crustaceans, and odonate nymphs, whereas it would indirectly increase numbers of benthic organisms, including tadpoles, chironomids, chaoborids, and oligochaeta (Maezono and Miyashita 2003). Although the trophic cascade effect was not investigated in this study, predation by *Cul. alburnus* may make it possible in the future to engineer similar top-down control responses in streams to which this predator has been introduced.

Management recommendations

Results of this study show that the introduced *Cul. alburnus* directly feeds on adult and young individuals of upper- and mid-water fish species. Long-term effects might decrease numerical abundances and change the age structure of fish populations and also cause local extinction of certain prey species. In addition, predation by *Cul. alburnus* may generate a trophic cascade through top-down control based on its diet (Polis and Strong 1996) or may induce control by its feeding on omnivorous fishes (Nowlin and Drenner 2000).

At the study sites of this study, the upstream movement of *Cul. alburnus* was blocked by a check dam. However, this study does not necessarily support the construction of check dams to serve as upstream obstructions to prevent fish invasions by both indigenous and exotic fishes. Evidence suggests that check dam construction in Taiwan has produced serious negative effects on stream habitats and organisms, including interference with the upstream migration of aquatic organisms (Tseng 1986), fragmentation and reduction of fish populations (Chang and Lin 1999), and homogenization of stream habitat structures (Chang and Lin 1999). Therefore, given all these negative impacts on stream habitats and animals, check dam construction does not represent an acceptable option to prevent invasions by indigenous and/or exotic lotic organisms.

Because *Cul. alburnus* is a tasty and delicious food fish, opening up areas invaded by this species without charge to fishermen to catch this species is a meritorious approach. Greater success might be gained if incentives for collecting *Cul. alburnus* are applied. However, educating anglers and the general public about not releasing young or adult *Cul. alburnus* into local waters may be the most effective way to control its further expansion in Taiwan. Overall, to protect aquatic biodiversity in Taiwan, reducing introductions by indigenous species should be given the same emphasis by administrative agencies and the general public as preventing invasions by exotic species.

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