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CHARACTERISTICS OF JAPANESE GIANT SALAMANDER (*ANDRIAS JAPONICUS*) POPULATIONS IN TWO SMALL TRIBUTARY STREAMS IN HIROSHIMA PREFECTURE, WESTERN HONSHU, JAPAN

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***Abstract*.—Habitat degradation threatens the Japanese Giant Salamander (*Andrias japonicus*) with extinction, and only limited baseline data on population structure, size, and density exist. We conducted a mark-recapture study of *A. japonicus* in two tributary streams within very different catchments in Hiroshima Prefecture between 2000 and 2003. In River A, a relatively undisturbed stream running through a wooded catchment, we captured a total of 87 individual salamanders, 54 juvenile and adult salamanders, and 33 larvae. River B is heavily disturbed compared to River A, and runs through an agriculturally-dominated catchment. We recorded 118 captures of 75 adults, but we caught no larvae in River B. Estimated population density and biomass was 1.3 and 1.2 individuals/100 m^2 and 85.9 and 167.3 kg/ha in Rivers A and B, respectively. Our results revealed that adult *A. japonicus* are abundant in both the relatively natural River A and the disturbed small stream, River B. Salamanders in River B were larger and heavier than those in River A, and consumed primarily frogs and other food items originating from rice paddy fields along the stream. However, it appears that larval recruitment is low in River B, possibly a result of stream alterations, which may eliminate spawning nests and larval habitat. Our data provide essential baseline information on *A. japonicus* populations including their density, biomass, and size distribution in these small streams. We suggest that a large-scale application of the approach used in this study may be useful for determining the effects of land use change on populations of this important species.**

Key Words.—*Andrias japonicus*; diet; habitat characteristics; Japanese Giant Salamander; land use; population structure

INTRODUCTION

The Japanese Giant Salamander, *Andrias japonicus* is the largest extant amphibian in the world, and is endemic to the three main islands of Japan – Honshu, Shikoku, and Kyushu (Matsui and Hayashi 1992; Matsui 2000). *Andrias japonicus* became a federally protected species under the "special natural monument" designation in 1952. It is also listed under Appendix I of the Convention on International Trade of Endangered Species (CITES) (Matsui and Hayashi 1992), and vulnerable in the Japanese Ministry of Environment's Red Data Book (Ministry of the Environment Government of Japan. 2006. The 3rd Version of the Japanese Red List on Birds, Reptiles, Amphibians, and Invertebrates. Available from http://www.env.go.jp/press/file_view.php?serial=8931 &hou_id=7849 [Accessed 15 January 2008]). Although collecting this species is prohibited throughout its geographic range (Matsui and Hayashi 1992), except for a few reserves, most of its habitat remains unprotected (Kobara 1985). Consequently, dams and bank protection walls constructed for flood and erosion control, agriculture, hydraulic power generation, and road construction severely impact a large portion of *A. japonicus*'s riverine habitat (Matsui 2000; Tochimoto 2005). Although rarely documented, this habitat degradation almost certainly negatively affects *A. japonicus* populations.

Though no rangewide recovery program for wild populations of this species have been implemented, conservationists have taken specific actions. For example, Asa Zoological Park researchers have successfully bred *A. japonicus* in captivity (Kuwabara et al. 1989). Also, others established experimental artificial nest boxes and dam by-pass structures that, in some cases, Giant Salamanders used (Tochimoto 2001, 2005).

Because habitat loss and degradation are among the most important causes of amphibian declines (Stuart et al. 2004), conservationists require information on how to evaluate habitats, as well as which habitat types should receive priority for preservation. *Andrias japonicus* occur in habitats ranging from relatively large rivers (20-50 m wide) to small tributary streams (1-4 m wide) (Tago 1931; Kawamichi and Ueda 1998; Sumio Okada, unpubl. data). Spawning nests and larvae of *A. japonicus* often occur in relatively small

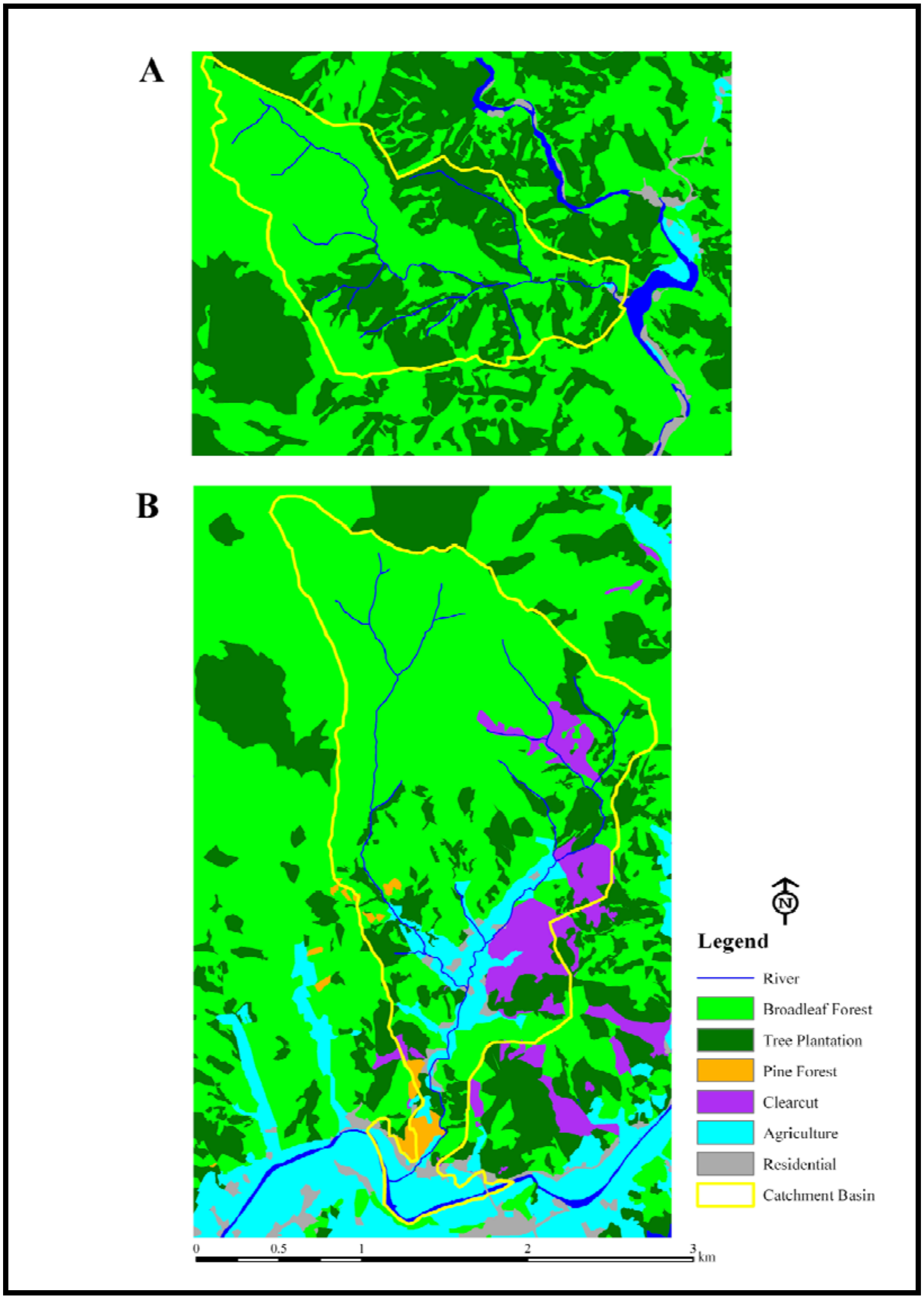

FIGURE 1. Distribution of land use categories in the catchment basin of River A (A), and River B (B), Hiroshima Prefecture, Japan. Map was produced using ERDAS IMAGINE 8.7 using orthorectified aerial photographs (Japan Forest Technology Association, 2003, 1/20000 scale) and was groundtruthed.

lotic habitats, including the upper reaches of tributary streams (e.g., Kobara 1985; Kawamichi and Ueda 1998). These small streams may be crucial for maintaining *A. japonicus* populations because they contain microhabitats for both nests and larvae. Despite the importance of this information, we know little about the ecology of *A. japonicus* in small streams, in particular the relationships between salamander

TABLE 1. Physical parameters of two rivers containing Japanese Giant Salamanders (*Andrias japonicus*), Hiroshima Prefecture, Japan.

River	Study reach length (m)	Bankfull stream width [mean (range)] (m)	Water depth [mean (range)] (cm)	Ave. water temperature (°C)	Channel slope (%)	Ave. elevation (m)
A	1020	4.0 (0.6-10.1)	31 (3-147)	17.3	4.9	355
B	1965	3.6 (1.1-9.2)	27 (2-80)	15.6	2.1	545

population size and structure, and physical attributes of habitats. Thus, conservation planning for Japanese Giant Salamander habitats and populations are difficult. In this study, we performed field surveys for *A. japonicus* in two small streams surrounded by very different land use patterns to describe: (1) population size, density, biomass and size distribution; (2) diet composition of salamanders; and (3) surrounding land use and in-stream habitat characteristics. These data serve as a case study and provide baseline information for future monitoring.

MATERIALS AND METHODS

Study site.—Our study took place along two tributary streams, Rivers A and B, in Hiroshima Prefecture, western Honshu, Japan. These streams are tributaries of the same river with River B situated approximately 20 km upstream of River A along the main branch. River A is a second-third order stream, and our study reach began at the confluence with a larger river and spanned 1020 m upstream (5673 m^2 total area). The reach contained two dams and one waterfall (Figs. 1A and 2A). Average stream width and depth at normal base flow were 4.0 m and 31 cm, respectively (Table 1). During 2002, water temperatures ranged from 9°C in November to 21°C in August, and averaged 17.3°C between May and September (Table 1). Discharge, measured once in June and July of 2002, averaged 0.62 ± 0.68 m^3 (range 0.14-1.1 m^3).

River B is a third-fourth order stream. Our study reach began at the confluence with a main branch and continued 1965 m upstream (7000 m^2 total area). This reach contained eight dams, including one at its up- and downstream ends (Figs. 1B and 2B). The upper 400 m of the study reach was divided into two second-order streams (Fig. 2B). Average stream width and depth at normal base flow were 3.6 m and 27 cm, respectively (Table 1). In 2002, water temperature ranged from 14.1°C in May to 21.1°C in August, and averaged 18.1° C between May and September (Table 1). Discharge, measured once in June and twice in July of 2002, averaged 0.11 ± 0.09 m^3 (range 0.11-0.26 m^3).

Survey techniques.—We performed eight nocturnal surveys (27 person hours) and 12 diurnal surveys (31 person hours) in River A, and 28 nocturnal surveys (76 person hours) and 13 diurnal surveys (26 person hours) in River B (Table 2). Surveys in both streams took place between 2000 and 2003.

Nocturnal surveys involved 1-3 people walking slowly from the downstream to the upstream end of a study reach with flashlights and capturing all visible salamanders with a dip-net. We also lifted rocks below dams to find salamanders. Diurnal surveys targeted larval salamanders and involved 1-3 people searching under piled rocks or leaves by hand or with a dip-net. We measured the total length (TL) and snout-vent length (SVL) of captured salamanders to the nearest 0.1 cm using a tape measure. We weighed salamanders with four different digital scales (salamanders with mass < 100 g weighed to the nearest 0.1 g, mass 100–999 g to the nearest 1 g, mass 1000–1999 g to the nearest 5g, mass >2000 g to the nearest 10 g). In 2000, we used photographs of head and tail spotting patterns to recognize individual post-metamorphic salamanders. In 2002 and 2003, we used both photos and Passive Integrated Transponder (PIT) tags (Biomark, Inc., Boise, ID) for identification. We injected PIT tags into the dorsum of a salamander at the base of their tail. In 2002 and 2003, we tagged larvae with Visual Implant Elastomer (VIE) tags (Northwest Marine Technology, Shaw Island, WA; Harvey 2003) along their body mid-dorsally, or on the side of their tail. We did not tag larvae in 2000. We recorded capture locations for each salamander on topographic maps (1:2,500).

We used swollen, doughnut-shaped cloacae to distinguish males from females (Tochimoto 1992; Kawamichi and Ueda 1998). We identified gravid females using their round, full abdomen and lack of cloacal swelling immediately before or during the breeding season (August to early September) (Tochimoto 1992). We considered all individuals except males with swollen cloacae and gravid females to be of unknown sex because the cloacae of all males do not swell during every breeding season (Tochimoto 1995).

TABLE 2. Japanese Giant Salamander survey effort in two rivers, Hiroshima Prefecture, Japan, including year and months of surveys and the number of surveys and person hours (pers.hrs) spent during nocturnal (noct.) and diurnal (diur.) surveys.

	River A			River B		
Year	Months	# of noct. surveys (pers.hrs)	# of diur. surveys (pers.hrs)	Months	# of noct. surveys (pers.hrs)	# of diur. surveys (pers.hrs)
2000	May-Jul.	7 (21)	6 (16)	Jun.-Oct.	9 (25)	5 (9)
2002	May-Nov.	1 (6)	5 (13)	May-Sep.	18 (48)	7 (15)
2003	Sep.	-	1 (2)	Apr.	1 (3)	1 (2)
Total		8 (27)	12 (31)		28 (76)	13 (26)

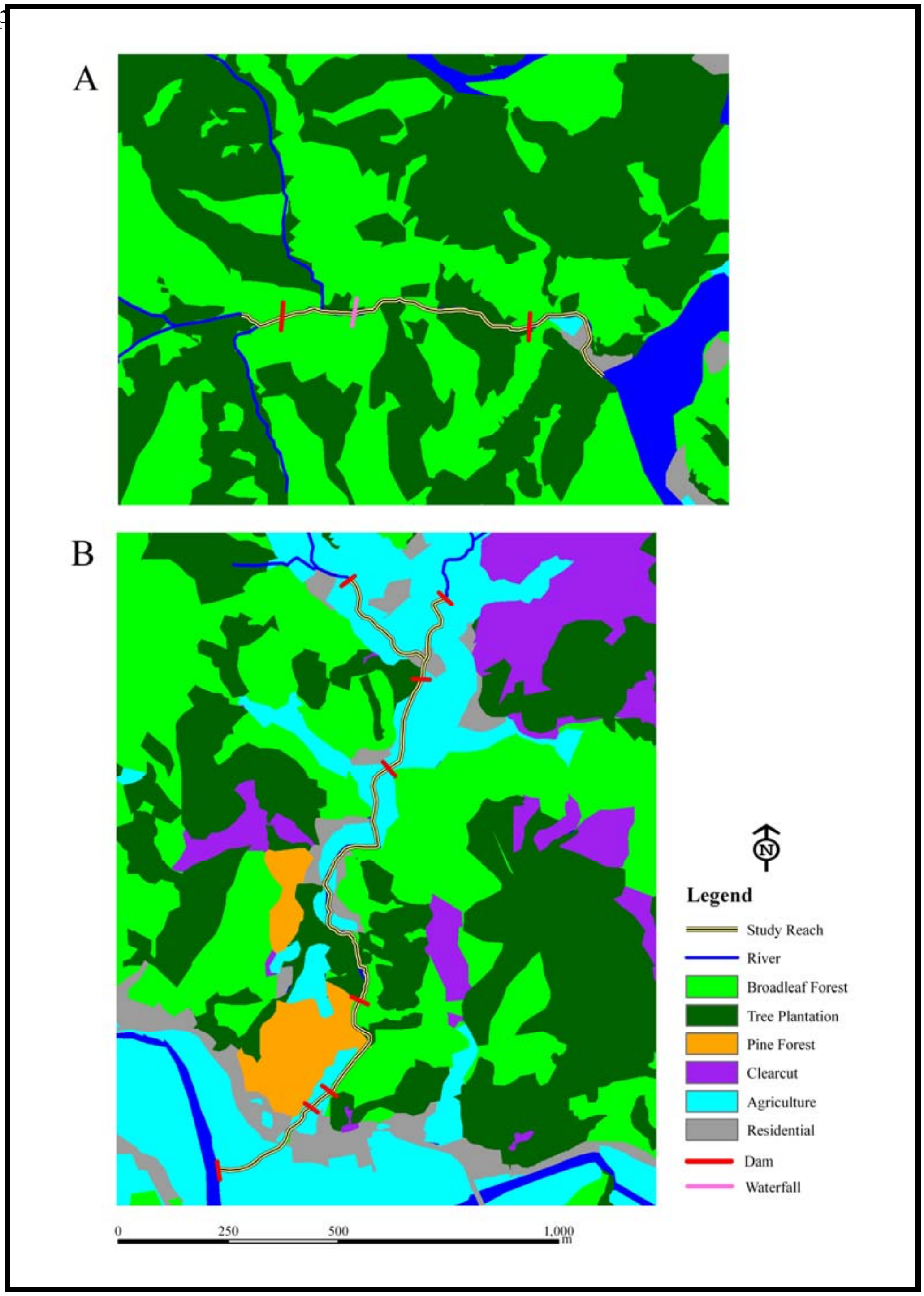

FIGURE 2. Distribution of land use categories adjacent to study reaches in River A (A) and River B (B), Hiroshima Prefecture, Japan. Map was produced using ERDAS IMAGINE 8.7 using orthorectified aerial photographs (Japan Forest Technology Association 2003, 1/20000 scale) and ground-truthed.

Salamander diet composition.—We stomach flushed (Fitzgerald 1989) 12 adult *A. japonicus* in River A and 11 adults in River B in June 2002 with a handheld aquarium pump (Cleaner Pump; GEX Corp., Osaka, Japan) to analyze their diets. We covered the suction end of the pump tube with a filter (TOPVALU Mizukiri-Gomibukuro stocking type, AEON Co., Ltd., Chiba, Japan) to exclude particulate matter and positioned it in the stream. We connected a 9 mm diameter, 100 cm long plastic tube to the drain side of pump. Soft rubber tubing (1 cm long, 9 mm diam.) covered the end of the plastic tube to prevent abrasion of the digestive tracts of salamanders. We hand-held salamanders and gently inserted the tubing through the salamander's mouth and into its stomach. We operated the pump by hand, and pumped stream water into the

TABLE 3. Estimated population size, density, and biomass of *Andrias japonicus* in two rivers, Hiroshima Prefecture, Japan.

River	Population size individuals ± SD	95% CI	Density individuals/100m^2	Biomass kg/ha
A	74 ± 12.9	56-108	1.3	85.9
B	86 ± 15.2	66-128	1.2	167.3

stomach until the returning water was clear and free of food items (See photographs in gallery). This usually entailed two or three repetitions of five pump squeezes. This procedure took two people approximately five minutes. We preserved stomach contents in 10% formalin and later identified them to the lowest possible taxonomic group (usually class or order). We measured wet mass of each item to the nearest 0.01 g using digital scales. We present stomach contents as frequency of occurrence (the proportion of individuals that contained the item) and percentage of total mass (percent of total mass of all stomach contents an item comprised).

Surrounding land use, river bank composition, rock density.—We used land use maps to reveal land utilization along each study reach and within each catchment. We orthorectified aerial photographs (Japan Forest Technology Association 2003, 1:20,000 scale) and digitized them using ERDAS IMAGINE 8.7. We used stereoscopes in interpretation of aerial photos. Land use maps were ground-truthed with a handheld GPS unit (Trimble Geo-XT, Trimble Navigation Ltd., Sunnyvale, California, USA) and modified during several visits to each study area between 2006 and 2007. We classified all areas within catchments into one of seven categories: (1) broadleaf forest; (2) tree plantation (Japanese Cedar, *Cryptomeria japonica*, and Hinoki Cypress, *Chamaecyparis obtusa*); (3) pine forest (Japanese Red Pine, *Pinus densiflora*); (4) clearcut; (5) agriculture; (6) residential; or (7) river. We estimated total length of each land use along the study reaches and the area of each land use in catchments using Arc GIS 9.0.

To assess availability of *A. japonicus* habitat, we quantified river bank composition by categorizing, to the nearest 10 cm, the entire length of each streambank in both rivers into either natural or artificial banks. Artificial bank walls are manmade and constructed of concrete or piled rocks. To quantify in-stream habitat, we tallied the number of rocks in three size classes (30-49 cm, 50-99 cm, over 100 cm) on crossing-sectional line transects at 20-m intervals for each study reach, and divided rock number by transect length to quantify density of rocks in each size class.

TABLE 4. Snout-vent length (SVL), total length (TL) and mass of juvenile and adult *Andrias japonicus* in two rivers, A (n = 78) and B (n = 54), Hiroshima Prefecture, Japan.

River	Mean SVL ± SD	Mean TL ± SD	Mean Mass ± SD
A	29.1 ± 6.3	44.5 ± 9.9	661 ± 858
B	35.9 ± 7.0	54.2 ± 9.7	1394 ± 821

Data analysis.—We estimated sizes of post-metamorphic salamander populations in both rivers with Program CAPTURE (Otis et al. 1978; White et al. 1982) using only data from 2000 surveys to reduce the risk of violating the closed population assumption. We calculated salamander biomass (kg/ha) as estimated density X mean mass of post-metamorphic salamanders. For salamanders in size classes that overlapped between the two rivers (25-39.9 cm SVL), we calculated a body mass index from the residuals of the regression of mass against SVL^3 (Brandt 2003). To determine whether size structure of salamander populations differed between streams, we first created a histogram of the number of salamanders captured per survey hour (nocturnal and diurnal surveys combined) in various size classes, and then used a Kolmogorov-Smirnov test to compare size distributions (SVL) between streams. We calculated a food mass index from the residuals of the regression of food mass against body mass. We used independent sample t-tests to compare average SVL, mass, and body mass and food mass indices between Rivers A and B, and SVL and mass between sexes within a river. We log-transformed body mass to meet normality assumptions. We used Mann-Whitney U-tests to compare density of rocks in three size classes (30-49 cm, 50-99 cm, > 100 cm) within riverbeds between Rivers A and B. We used χ^2 to test the null hypotheses that the length of each land use along stream reaches, the area of each land use within catchments, and the length of natural and artificial banks occurred in the same proportion in Rivers A and B. For all tests, $\alpha = 0.05$. All means are reported as ± 1 standard deviation (SD).

RESULTS

Population size, density, and biomass.—In River A, we recorded 70 captures of 54 individual salamanders (47 adults and 7 juveniles), and captured at least 33 individual larvae (total 39 captures). We recaptured 12 adult salamanders once and two adults twice. We did not recapture any tagged larvae. In River B, we recorded 118 captures of 75 individuals. No larvae or juveniles were captured. We recaptured 20 adults at least once and recapture frequency ranged 1-5 times. Estimated sizes of post-metamorphic salamander populations were 74 ± 12.9 (95% CI = 56-108) and 86 ± 15.2 cm (95% CI = 66-128) individuals in Rivers A and B, respectively (Table 3). Although estimated density was similar in both streams (1.3 and 1.2 individuals/100 m^2 in Rivers A and B, respectively), estimated biomass

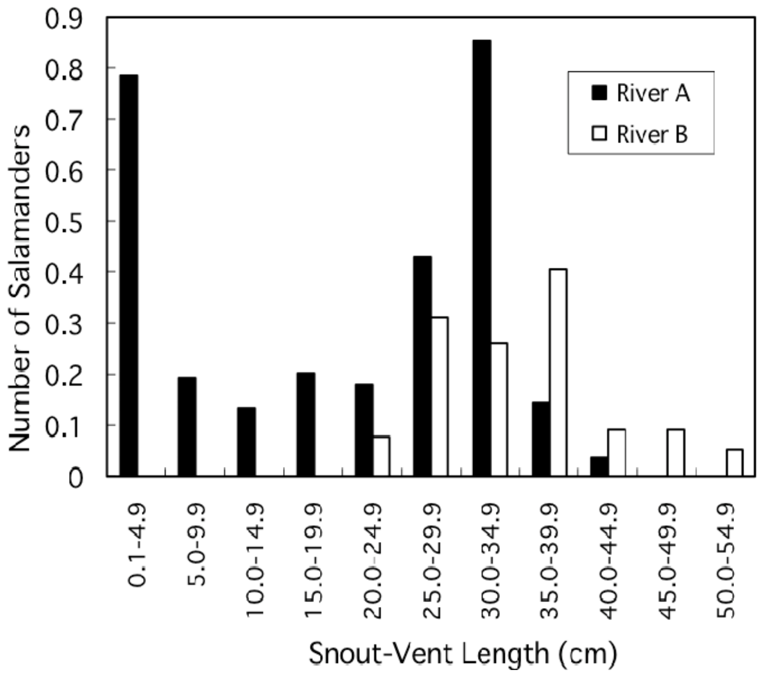

FIGURE 3. Body size histogram of snout-vent length of *A. japonicus* in two rivers, Hiroshima Prefecture, Japan. Solid bars show number of salamanders in River A, open bars show number of salamanders in River B.

in River B (167.3 kg/ha) was approximately twice that of River A (85.9 kg/ha) (Table 3).

Population structure.—In River A, 40 of 87 individuals (46.0%) were larvae or juveniles (< 20 cm SVL), whereas we did not record these size classes in River B (Fig. 3). Salamander size (SVL) distribution differed significantly between Rivers A and B ($D = 0.49$, $P < 0.001$). Size distribution was bimodal in River A with one group of salamanders peaking at approximately 5 cm SVL and another peaking at 30-34.9 cm SVL. In River B, salamander size was unimodal with one peak at 35-39.9 cm SVL.

In River B, we captured 17 males, three females, and 10 unknowns (5.7 males:1 female), and eight males, two females, seven unknowns (4 males:1 female) between July and September of 2000 and 2002, respectively. Mean SVL did not differ between males and females (38.7 ± 8.2 and 32.3 ± 3.4 cm, respectively; $t = 1.70$, df = 28, $P = 0.10$). The average mass of males, 1781 ± 1110 g, did not differ from that of females, 1030 ± 275 g ($t = 1.10$, df = 28, $P = 0.28$). In River A, we captured 10 males (mean SVL = 34.6 ± 4.5) but observed no females.

Body size relationships.—In River A, larval salamanders averaged 5.0 ± 2.9 mm SVL, and 7.6 ± 11.9 g body mass. The largest larva with external gills was 12.9 cm SVL (19.4 cm TL, 53.1 g mass). The smallest salamander with open gill slits, but without external gills was 14.3 cm SVL (20.4 cm TL, 61.1 g mass), and the smallest individual with closed gill slits was 15.8 cm SVL (22.9 cm TL, 71.9 g mass).

Mean SVL of post-metamorphic salamanders was lower in River A (29.1 ± 6.3 cm) than River B (35.9 ± 7.0 mm; $t = 5.73$, df = 127, $P < 0.001$; Table 4). Mean mass of post-metamorphic salamanders was lower in River A (661 ± 352 g) than River B (1394 ± 858 g; $t = 6.62$, df = 127, $P < 0.001$; Table 3). Average body mass index was greater for River B than River A ($t = -3.40$, df = 92, $P = 0.01$).

Salamander diet composition.—We obtained 44 prey items totaling 50.77 g wet mass from 12 salamanders in River A, and 45 prey items totaling 181.21 g wet mass from 11 salamanders in River B (Table 5). Mean SVL and mass of stomach-flushed salamanders were 30.3 ± 6.0 cm and 690 ± 339 g in River A, and 39.8 ± 7.9 cm and 1795 ± 1127 g in River B. Food mass index was significantly higher in River B than River A ($t = -2.87$, df = 21, $P = 0.009$).

In River A, there were four food and two non-food categories consumed by *A. japonicus*. Freshwater crabs occurred in 92.3% of individuals, showing the highest frequency of occurrence and the highest proportion of total stomach contents by mass (35.1%). Fish were the second most important food category and occurred in 46.2% of individuals (29.7% total stomach contents mass). Aquatic insects occurred in 23.1% of individuals (8.7% total prey mass; Table 5). Small rocks and plants (leaves, twigs, roots), non-food items, comprised 22% and 4% of wet mass of all stomach contents, respectively. Ninety-seven percent of the total mass of all food items (total food items minus non-

TABLE 5. Diet composition (%) of *Andrias japonicus* in two rivers, A (44 prey from 12 salamanders, total weight 50.77g), and B (45 prey from 11 salamanders, total weight 188.21g) in June 2002.

	Frequency of occurrence		Proportion of prey mass	
Prey type	River A	River B	River A	River B
Snake	-	9.1	-	11.5
Frog	-	63.6	-	56.0
Fish	46.2	27.3	29.7	24.3
Freshwater crab	92.3	18.2	35.1	1.8
Insects (terrestrial)	23.1	36.4	0.5	1.0
Insects (aquatic)	23.1	27.3	8.7	1.2
Earthworm	-	9.1	-	0.7
Spider	-	9.1	-	0.3
Freshwater shrimp	-	9.1	-	< 0.1
Plants	30.8	63.6	4.0	1.1
Rocks	46.2	18.2	22.0	2.1

food items) were items that originated from within the stream, such as freshwater crabs, fish, and aquatic insects, and 2.7% of total food item mass was insects that originated from adjoining terrestrial or rice paddy habitats.

In River B, salamanders consumed nine food and two non-food categories (Table 5). Frogs occurred in the highest proportion of River B salamanders (63.6%), and showed the highest proportion of total stomach contents mass (56% of total mass). In terms of frequency of occurrence, the second most important prey categories were terrestrial insects (36.4%). Fish and aquatic insects both occurred in 27.3% of individuals. In terms of proportion of total stomach contents by mass, the second and third highest categories were fish (24.3% of total) and snakes (11.5% of total). Frogs, the most important prey category in terms of occurrence and mass, included species such as *Rana nigromaculata*, which breed in paddy fields along the stream. Twenty-eight percent of the total mass of food items (total stomach contents minus non-food items) originated in the stream, including fish, aquatic insects, freshwater crabs, freshwater shrimp and 72% originated outside of the stream, including a snake, frogs, insects, earthworms, and spiders. We observed the frogs *Rana nigromaculata*, *R. ornativentris*, *Hyla japonica, Rhacophorus areboreus*, and *R. schlegelii* breeding in paddy fields along the study reach of River B.

Surrounding land use, river bank composition, rock density.—The area of seven land use categories occurred in the different proportions within the catchments of Rivers A and B (χ^2 = 110.2, df = 6, P < 0.001). Whereas broadleaf forest and tree plantations covered nearly the entirety of the catchment basin of River A (99% of total area), the catchment basin of River B contained tree plantations, agriculture, and clearcuts (each < 8% of total) in addition to broadleaf forests (66 % of total; Table 6; Fig. 1A and B). The length of these seven land use categories immediately adjacent to Rivers A and B did not occur in the same proportions (χ^2 = 2456, df = 6, P < 0.001; Table 7; Fig. 2A and B). Along the study reach, agriculture was the largest category (66%) for River B, followed by broadleaf forest and residential areas (both comprising 12.6% of total length). In River A, broadleaf forest (47.8%) and tree plantation (36.9%) were the largest categories. A greater proportion of the total bank length of River B was composed of artificial banks compared to River A (χ^2 = 2456, df = 1, P < 0.001; Table 8). Median density of rocks in the 30-49 cm, 50-99 cm, and > 100 cm size classes were significantly higher in River A than River B (Table 9).

Habitat and shelter use.—Although we searched habitats similar to those in River A where larvae occurred, searches of River B revealed no larvae. Eight of nine larger larvae (> 1 year-old, 6.2-12.9 cm SVL) occurred under rocks (5-21 cm water depth) and one was active. A random sample of 17 salamanders (eight larvae and nine postmetamorphic salamanders) found under rocks showed that salamander SVL (range 3.1-36.8 cm) was positively related to area (cm^2) of rock used for shelter (range 600-6489 cm^2; r^2 = 0.28, df = 16, P = 0.03). In River B, in addition to natural rocks, adult salamanders used broken concrete slabs or artificial bank walls as shelter. In River A, 27 out of 30 one year-old larvae were found in leaf-litter packs, and three one year-old larvae were found under rocks. Eight larger larvae (> 1 year-old) were found under rocks as well.

DISCUSSION

Population size, density and biomass.—Estimated salamander densities from this study (River A: 1.3/100 m^2, River B: 1.2/100 m^2) are similar to streams in Tottori Prefecture (Okada 2003), suggesting that *A. japonicus* was relatively abundant in the streams we studied. Because we did not use larval data in density calculations, we probably underestimated the density of *A. japonicus* in River A where we regularly encountered larvae. Biomass in River A (89.2 kg/ha) was similar to streams in Tottori Prefecture (Okada 2003) whereas River B had a relatively high biomass (167.3 kg/ha). These results were unexpected because River B was more affected by forestry, agriculture, artificial bank walls, and contained low rock density compared to River A. Kawamichi and Ueda (1998)

TABLE 6. Area (ha) and percentage of total area comprised by seven land use categories from within the catchment basins of two rivers, Hiroshima Prefecture, Japan.

Land use category	River A Area (ha)	River A Percentage of total (%)	River B Area (ha)	River B Percentage of total (%)
Broadleaf forest	228.0	66.1	323.2	66.1
Tree plantation	116.2	33.7	63.6	13.0
Pine forest	0	0	5.4	1.1
Clearcut	0	0	42.8	8.7
Agriculture	0.3	0.1	44.0	9.0
Residential	0.5	0.1	7.2	1.5
River	0	0	2.9	0.6
Total	345	100	489	100

recorded 103 individual *A. japonicus* within a 1.2 km reach of a 1-4 m wide stream in Hiroshima Prefecture, but did not describe density and biomass of *A. japonicus* per unit area. Average density and biomass of *A. japonicus* from five 2nd-4th order tributary streams in Tottori Prefecture were 1.2/100 m^2 (range = 0.4-2.0) and 70 kg/ha (range = 31.8-119.6 kg), respectively (Okada 2003).

Population structure.—In River A, 40 of 87 individuals (46.0%) were larvae or juveniles less than 20 cm SVL, indicating reproduction and recruitment are occurring. In River B, however, we did not record these younger size classes and many individuals in this population were larger than those in River A. The lack of smaller size classes may indicate that there are low reproduction rates in River B, and that this population is one of conservation concern. Declining Hellbender (*Cryptobranchus alleganiensis*) populations show a decrease in frequency of small individuals and a preponderance of larger, hence older, individuals (Wheeler et al. 2003). Without historical data for comparison, it is difficult to judge whether the size of a population is stable or declining. Because long-lived species such as *A. japonicus* and *C. alleganiensis* (e.g., Wheeler et al. 2003) exhibit relatively slow population responses, continued periodic monitoring of these populations is warranted.

In River B, the male:female sex ratio was 5.7:1 in 2000 and 4:1 in 2002. Because our counts of females included only gravid salamanders, the sex ratios we observed can be regarded as effective sex-ratios. Male-biased effective sex-ratios such as those in River B have been observed during spawning congregations (Kobara 1985; Kawamichi and Ueda 1998). At two nests observed by Kawamichi and Ueda (1998), there were 13 males and four females (3.3:1), and three males and two females (1.5:1). Another spawning congregation at a nest contained 19 males and eight females (2:1) (Kobara 1985). We observed 25 males, five females, and 17 unknowns from July to September in 2000 and 2002. Some of the 17 unknowns were likely non-gravid females.

Kawamichi and Ueda (1998) reported that the smallest male and female participating in spawning congregations was 30 cm and 40 cm TL, respectively. Kobara (1985) reported the smallest sexually mature male as 29.5 cm TL, the smallest mature female as 30-35 cm TL. The smallest male observed by Okada (2006) was 26.7 cm TL. The smallest male in the present study was 32.2 cm TL (22.9 cm SVL), and the smallest female was 44.5 cm TL (27.5 cm SVL), both captured in River B. Size of *A. japonicus* at sexual maturity in River B was similar to past studies, though age at maturity was unknown.

Habitat and shelter use.—Searches of habitats similar to River A that occurred in River B revealed no larvae. Salamander SVL was positively related to the size of shelter rock. Smaller *A. japonicus* life stages likely use interstitial spaces within streambeds as shelters. Larval Hellbenders used interstitial spaces in gravel beds, which contained invertebrates consumed by larvae (Nickerson et al. 2003). River B had fewer rocks than River A, and thus, microhabitat for larvae and juveniles could be limited. The stream bed of River B was relatively embedded by sand and small gravel (Sumio Okada and Taeko Utsunomiya, pers. obs.), and agricultural activities may have contributed to these alterations. Agriculture has contributed to

TABLE 7. Length (m) and percentage of total length comprised by seven land use categories immediately adjacent to the banks two rivers, Hiroshima Prefecture, Japan.

Land use category	River A Length (m)	River A Percentage of total (%)	River B Length (m)	River B Percentage of total (%)
Broadleaf forest	975.4	47.8	493.4	12.6
Tree plantation	753.2	36.9	302.5	7.7
Pine forest	0	0	46.1	1.2
Clearcut	0	0	0	0
Agriculture	105.9	5.2	2594.9	66.0
Residential	205.5	10.1	493.1	12.6
River	0	0	0	0
Total	2040	100	3930	100

sedimentation in other watersheds (Tinker 1997; Bacey and Sprulock 2007). In River B, at least 12 different salamanders sheltered beneath the same concrete slab, and five other salamanders used other concrete slabs or artificial rock wall as shelters. These observations suggest that though adult *A. japonicus* will use a variety of artificial objects as shelters, larvae may have more restrictive habitat requirements.

Salamander diet composition.—Stomach contents examined by Tago (1931) were 80% freshwater crab and 20% fish. Other reports demonstrated that *A. japonicus* preys on numerous items, including freshwater crab, fish, frogs, snakes, small mammals, turtles, and insects (reviewed by Tochimoto 2002). We obtained four and nine food categories from Rivers A and B, respectively, including freshwater crabs, fish, frogs, snakes, insects, earthworms, spiders and freshwater shrimp. These data suggest that *A. japonicus* is an opportunistic predator in these rivers.

Salamanders in River B had higher food mass indices than those in River A. In River A, freshwater crabs were the dominant food item, whereas frogs dominated diets in River B. The study reach in River B was largely contiguous with agriculture (> 90% paddy fields). These paddy fields are relatively stable in time and space (Saito et al. 1988) and foster the production of many organisms such as benthos, plants, insects, fish, frogs, and snakes (Saito et al. 1988; Hasegawa and Tabuchi 1995; Hidaka 1998). We suggest that terrestrial energy subsidies, especially frogs, provided by rice paddies are important to food webs in some rivers containing *A. japonicus*. Terrestrial subsidies can greatly influence the shape and stability of aquatic food webs (Kawaguchi and Nakano 2001; Woodward and Hildrew 2002). In North Carolina streams, eliminating terrestrial inputs to streams by excluding litter fall reduced the growth rate and biomass of aquatic salamander larvae and led to increased consumption of terrestrial food items (Johnson and Wallace 2005). This phenomenon may have impacted *A. japonicus* in River B, leading to increased biomass of the species and heavier-bodied individuals. However, this study was unreplicated so we can only speculate about the effects of surrounding terrestrial systems on the aquatic food webs that include *A. japonicus.*

This study provides essential information on *A. japonicus* populations such as density, biomass,structure, and diet composition and is useful for generating hypotheses regarding relationships between habitat characteristics and population size and structures in tributary streams. Our results suggest that detailed investigations of the size structure of *A. japonicus* populations are required when assessing the status of populations. While the population of *A. japonicus* in River B showed approximately equivalent density (individuals/100m^2), and higher estimated biomass and average body mass index, compared to the population in River A, the population in River B showed no signs of recent reproduction. However, we studied only two streams, which represent one type of habitat in which *A. japonicus* occurs. *Andrias japonicus* commonly inhabits larger tributary and main streams. This study can be a useful case study for similar future investigations. Further studies should encompass larger scales (e.g., a river system) to reveal trends in *A. japonicus* population demography across gradients in land use from relatively natural watersheds to those dominated by human-related activities through a combination of periodic field surveys and GIS analysis. Detailed stomach contents analysis utilizing stable isotope techniques (Cabana and Rasmussen 1996) in a variety of watersheds would help elucidate the role of terrestrial systems such as rice paddies in structuring the aquatic food webs whose top predator is *A. japonicus*.

TABLE 9. Density of rocks in three size classes in two rivers, Hiroshima Prefecture, Japan. Density was estimated from cross-sectional line transects measured every 20 m along each study reach. Mann-Whitney U tests compared median density of rocks in each size classes between the two rivers.

	Density/10m (median ± interquartile range)		
Rock size	River A	River B	Mann-Whitney U
30-49 cm	5.2 ± 9.4	0.0 ± 3.3	1245, $P < 0.001$
50-99 cm	3.6 ± 7.3	0.0 ± 0.0	1239, $P < 0.001$
>100 cm	0.0 ± 2.6	0.0 ± 0.0	1566, $P < 0.001$

TABLE 8. Length (m) and percent of total bank length composed of natural bank vs. artificial bank in two rivers, Hiroshima Prefecture, Japan.

Bank type	River A	River B
Natural	1689 (82.8%)	2431 (61.9%)
Artificial	351 (17.2%)	1499 (38.1%)

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