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4   The effectiveness of catch and release fishing in

5   sustainable use of stream-dwelling salmonids populations

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7   （河川性サケ科魚類におけるキャッチアンドリリースの資源維持

8   効果に関する研究）

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Preface

Recreational fisheries are having a large impact on fish populations as well as commercial fishieries (e.g., Coleman et al. 2004; Grimm 2004; Lewin et al. 2006). The management of recreational fishing has received considerable attention (Lewin et al. 2006). Arlinghaus et al. (2002) categorized the regulations for recreational fishing as technical measures (e.g., closed area, closed season, gear restrictions), input controls (access and effort control, e.g., examinations, licenses), and output controls (e.g., catch limit, size limit, catch and release). Among these regulations, catch and release is distinctive and complex. Catch and release fishing is a method for sustaining fishing resources via the release of caught fish (Fig. 1.1). The ultimate success of catch and release fishing hinges on ensuring high survival rates for released individuals by minimizing injury and mortality (Wydoski 1977; Bartholomew and Bohnsack 2005). However, caught fish suffer from substantial stress (e.g., hook punctures, fighting until landing, and handling). Because the destiny of caught and released fish is invisible, its effectiveness for sustaining fish resources is uncertain, even though all fishermen comply with the regulation. Thus, follow-up researches of caught and released fish are essential to evaluate the effectiveness.

Initially catch and release fishing was mainly a by-product of regulations limiting the size, number, or species of fish that could be retained (Policansky 2002). Today, catch and release fishing is a well-established practice of recreational fishermen and a

3

1   useful option for fisheries management (e.g., Cooke and Suski 2005; Cooke and

2   Schramm 2007). Cooke and Cowx (2004) estimated that 19 million tons of fish,

3   representing over 30 billion individuals, are caught and released globally into

4   recreational fisheries. This is equal to the amount of fish (17.9 – 39.5 million tons) that

5   are discarded each year by commercial fisheries around the world (Alverson et al. 1994).

6   Overall, it is estimated that approximately 60% of the fish caught by recreational

7   fishermen in North America are released (Cooke and Wilde 2007). Catch and release

8   fishing is becoming established in Japan. For example, more than 30 rivers in Japan

9   have catch and release areas for salmonids (Tanaka 2003).

10   Catch and release fishing is particularly applicable to oligotrophic and cold waters,

11   where even moderate fishing effort can lead to exploitation that exceeds annual surplus

12   production (Noble and Jones 1999). In moutain streams, where recreational fish

13   populations are predominantly salmonids (Griffith 1999), water areas are small and

14   fishing intensity tends to be very high (Cox and Walters 2002; Tsuboi and Endou 2008,

15   see also Chapter 2 in this dissertation). Japanese mountain streams are habitats of

16   stream-dwelling salmonids, white-spotted charr (*Salvelinus leucomaenis*), masu salmon

17   (*Oncorhynchus masou*), and red-spotted masu salmon (*O. masou ishikawae*), which are

18   usually non-anadromous and important resources for recreational fishing. These

19   salmonids appear to be exposed high fishing intensity during juvenile to adult stage.

20   Consequently, these salmonids are high priority for the study of evaluation of catch and

21   release fishing for sustaining resources.

22   To evaluate the effectiveness of catch and release fishing on stream-dwelling

23   salmonids, firstly the exploitation rate should be assessed (i.e., the fraction of the fish in

24   a population that is caught and removed during a particular effort). It is also important

1   to research the phenotypic characteristics concerning about the selectivity by

2   recreational fishing. Here, "selectivity" was defined as the trend which specific

3   individuals are easier to be caught. Then, caught and released fish should be followed

4   up. It is important to assess the growth, survival and vulnerability to fishing after catch

5   and release. Here, "vulnerability to fishing" was defined as the probability of being

6   caught, which differs among individuals and may be altered by learning the hook

7   through the experience(s) of caught and released.

8   There have been numerous studies of the hooking mortality associated with

9   various types of fishing equipment and in various species. One study found that the

10   average hooking mortality for non-anadromous trout was 31.4 % with bait fishing

11   (reviewed by Taylor and White 1992). Many studies of hooking mortality have

12   indicated that the mortality of fish hooked in vital organs such as the esophagus or

13   gills (i.e., deep-hooked fish) is very high for some species (reviewed by Taylor and

14   White 1992; Muoneke and Childress 1994; Bartholomew and Bohnsack 2005). It has

15   been suggested that cutting the fishing line rather than removing the hook can reduce

16   the post-release mortality of deep-hooked fish (e.g., Mason and Hunt 1967; Schisler

17   and Bergersen 1996; Schill 1996).

18   Although the hooking mortalities of various species are well known, the study of

19   growth and vulnerability to fishing after catch and release are rarely done and

20   undeveloped. Siepker et al. (2006) observed decreased feeding by largemouth bass

21   (*Micropterus salmoides*), subsequent to be caught and released, whereas fishing had

22   no effect on the growth rates of rainbow trout (*O. mykiss*, Mason and Hunt 1967),

23   white-spotted charr (Doi et al. 2004), and largemouth bass (Pope and Wilde 2004).

24   The vulnerabilities of carp (*Carprinus carpio*) and rainbow trout were shown to

1 decrease after catch and release (Beukema 1970; Yoneyama et al. 1996), although

2 catchable tilapia (*Tilapia mossambica*) were caught repeatedly (Yoneyama et al.

3 1992).

4   Almost all studies that have investigated hooking mortality, the fate of hooks left in

5 released fish, and growth and vulnerability to fishing subsequent to release have been

6 conducted in pens or artificial ponds (except for Schill et al. 1986; Schill 1996). Schill

7 (1996) suggested that studies in lentic water (i.e., artificial ponds) with hatchery fish

8 may not be useful for describing hooking mortality in natural streams. Since such an

9 artificial habitat is vastly different from the natural environment (e.g., food, habitat

10 density, predation pressure, substrate, water velocity), it is difficult to evaluate the

11 effectiveness of catch and release. Hooking mortality might be overestimated in lentic

12 water, where the incidence of deep hooking increases because it is hard to detect the bite

13 of fish. Indeed, a study in a natural stream reported lower hooking mortality (16%) than

14 that reported in most previous studies (mean = 25%) for rainbow trout (Schill 1996).

15 Therefore, it is important to investigate the effects of catch and release fishing on fish in

16 the natural environment, in order to evaluate its effectiveness for sustaining resources

17 and to appropriately review previous studies.

18   The reasonable approaches for evaluation of effectiveness of catch and release on

19 stream-dwelling salmonids are fishing experiments in small mountain streams, where

20 almost all fish can be identified. The four things should be evaluated, 1. the exploitation

21 rate by single fisherman in various habitats to assess the impact of recreational fishing

22 on stream-dwelling salmonids, 2. the growth, survival, and vulnerability to fishing after

23 single catch and release experiment in several streams, 3. the phenotypic characteristics

24 concern about the selectivity of fishing and the magnitude of learning the hook through

the experience(s) of being caught and released via multiple catch and release fishing experiments, 4. the effectiveness of cutting the fishing line on deep-hooked fish for minimizing the hooking mortality.

In this dissertation, I have documented the magnitude of the impact of fishing on fish populations and the effectiveness of catch and release fishing for sustaining resources of stream-dwelling salmonids (Fig. 1.1). First, I examined the relationships between catch per unit effort (CPUE) and abundance in a mountain stream for two sympatric salmonids, the white-spotted charr and the red-spotted masu salmon (Chapter 2). Second, I examined the effects of a single catch and release fishing event on growth, survival, and vulnerability to future fishing for white-spotted charr (Chapter 3). Third, I investigated the effects of phenotypic variation and experience of being caught on vulnerability to fishing for white-spotted charr, through a multiple catch and release experiment (Chapter 4). Fourth, I followed the fate of deep-hooked white-spotted charr released by cutting the fishing line (Chapter 5).

1   encouragement.

2

1

2

3   **Fig. 1.1.** Schematic diagram explaining the catch and release fishing. I evaluated the

4   magnitude of the impact of fishing on fish populations (chapter 2), the effects of a catch

5   and release fishing on individuals (chapter 3), the selectivity of fishing through a

6   multiple catch and release experiment (chapter 4), and a method for reducing hooking

7   mortality just after fishing (chapter 5).

8

2

Exploitation rates and relationships between catch per unit effort and abundance of salmonids in a mountain stream

2-1. Introduction

The exploitation rates by recreational fishing are elementary information to assess the magnitude of fishing impacts on fish populations (Lewin et al. 2006). Annual exploitation rates by recreational fishing range from < 10% to > 80% (Lewin et al. 2006). For example, annual exploitation rates estimated 14–60% in rainbow trout (Cox and Walters 2002) and 48–50% in sockeye salmon (*O. nerka*, Matsuishi et al. 2002). Exploitation rates by recreational fishing differ also between sympatric species. Using population models, exploitation rate of cutthroat trout (*O. clarki*) was 2.5 folds greater than that for brook trout (*S. fontinalis*, Paul et al. 2003), therefore, fishing is one of factors to determine distributions of both species (Dunham et al. 2002). Although the information of exploitation rates of more than two sympatric species is important in discussing fishery management, it rarely has been assessed in the fisheries literature (Holtby et al. 1992, Paul et al. 2003).

The relationship between recreational fishing and abundance is also important as well as exploitation rate. Catch per unit effort (CPUE) is often used to assess fish populations within commercial and recreational fisheries, and strict proportionality between CPUE and abundance is frequently assumed (Harley et al. 2001). However, this assumption of proportionality is not expected to apply to all populations. Clark

10

1   (1985) proposed various forms of the CPUE-abundance relationship. "Hyperstability"

2   occurs when CPUE remains high while abundance drops, whereas "hyperdepletion"

3   occurs when CPUE declines much faster than abundance (Hilborn and Walters 1992).

4   Hyperstability is an especially serious problem, because it results in the overestimation

5   of abundance from CPUE data. Such overestimations have been documented in not only

6   commercial fisheries (Matsuishi et al. 1993; Harley et al. 2001; Gaertner and

7   Dreyfus-Leon 2004) but also recreational fishing (Peterman and Steer 1981; Bannerot

8   and Austin 1983). However, there have been no studies about the relationship between

9   CPUE and abundance in mountain streams.

10   In this chapter, I examined the exploitation rates and the relationships between

11   CPUE by hook-and-line fishing and abundance within pools in a mountain stream to

12   assess the magnitude of the effect of fishing on fish populations.

13

14   **2-2. Materials and methods**

15   *Study area*

16   The field study was conducted in the Ara Stream (35°48'N, 138°35'E; Fig. 2.1), a

17   tributary of the Fuji River, in central Japan. Deciduous and conifer forest canopy

18   covered approximately 20-40% of the stream width. White-spotted charr and

19   red-spotted masu salmon have a non-anadromous life history (Endou et al. 2006). The

20   study area is open to fishing from March to September, but there has been no stocking

21   of hatchery-reared fish for several decades.

22   *Fishing experiments and underwater observations*

23   I measured the area of 92 pools in March 2004. The center length of each pool was

24   measured (cm). Stream width was measured (cm) at three evenly spaced transects along

1   the length of each pool. Pool size ranged from 7.35 to 396.58 m^2 (63.4 ± 69.0 m^2, mean

2   ± SD).

3   Fishing experiments were conducted from 8 May to 6 June 2004. I fished in all

4   pools during daylight using a 6.1-m carbon rod, 1.5-lb fluorocarbon line (diameter:

5   0.076 mm), a 1/128-oz sinker, a single barbed hook (gape width: 5.0 mm), and a live

6   bait (caddisfly larva *Stenopsyche marmorata*, body length: 15.1 ± 3.6 mm, mean ± SD).

7   The duration of fishing was determined based on pool area at 0.5 min / m^2, making

8   fishing effort per pool area equal in all pools. Therefore, the relationship between CPUE

9   and fish density correspond to the relationship between the number of fish caught per

10   fishing in a pool and the number of fish in a pool. I assumed the number of fish caught

11   per fishing in a pool as the CPUE of each species in each pool. To the extent possible,

12   the bait was naturally drifted or dropped down into all areas of the study pools.

13   Captured fish were released into their original pool immediately after the fishing period.

14   Water temperature was 10.4 ± 2.1 °C, which is within the preferred feeding range of

15   white-spotted charr and masu salmon (Takami et al. 1997; Takami and Sato 1998).

16   Shortly after fishing was complete, I counted the fish in each pool by underwater

17   observation using snorkeling gear. I assumed negligible fish migration (i.e., none

18   entered or exited the pool between fishing and snorkeling), because white-spotted charr

19   and red-spotted masu salmon are strongly resident during the non-breeding season

20   (Nakano et al. 1990; Nakamura et al. 2002; Sakata et al. 2005). I was equipped with a

21   wetsuit, mask, and snorkel and entered at the lower end of each pool, then crawled

22   slowly upstream in a zigzag pattern (Thurow 1994). Observed salmonids were

23   identified to species, counted, and classified into three groups (total body length: <100,

24   100–199, ≥200 mm). Newly emerged fry (age-0+ fish) were not counted. The ability

1   to count fish by snorkeling varies along with personal skill or clearness of water, giving

2   estimates that are 40-80 % of those based on electrofishing (Rodgers et al. 1992;

3   Thurow and Schill 1996; Mullner et al. 1998). In this observation, however almost all

4   fish could be seen because the water is very clear in Japanese mountain streams and

5   horizontal visibility is generally as far as 6 m. In addition, a waterproof headlight was

6   used to find fish hiding behind rocks. After snorkeling, 25 of 92 pools were fished using

7   an electrofisher (Smith-Root, Inc., Vancouver) and a dip net in two depletion passes

8   (Zippen 1958) to obtain population estimates using the computer program CAPTURE

9   (White et al. 1978). There was no significant difference for either species in the

10   numbers counted by snorkeling and estimated by electrofishing (paired t-test,

11   white-spotted charr: df = 14, p = 0.105, red-spotted masu salmon: df = 14, p = 0.215).

12   The correlation coefficients between snorkeling and electrofishing were sufficiently

13   high (white-spotted charr: r = 0.840, red-spotted masu salmon: r = 0.853). Therefore, I

14   used the number of fish counted by snorkeling as the abundance of each species in each

15   pool.

16   *Statistical analyses*

17   Data for statistical analyses were collected from 88 pools; 4 pools were omitted

18   because they lacked fish. White-spotted charr were found in 65 pools, and red-spotted

19   masu salmon were found in 64 pools; both species were found in 41 pools. I assumed

20   that the number of fish caught in a given fish abundance per unit of effort is modeled

21   as a Poisson distribution.

22   First, I examined whether abundance was related to CPUE using a GLM. The

23   best-known GLM for count data assumes a Poisson distribution (Agresti 2002).

24   Estimated likelihood ratios were tested using chi-square tests (Hardy 2002).

1   Additionally, I examined whether the relationship between CPUE and abundance

2   was proportional. The simplest model relating the abundance of fish to CPUE assumes

3   a proportional relationship (Peterman and Steer 1981):

4

5    $$U_i = qA_i$$

6

7   where U_i is the CPUE in pool i, q is the catchability coefficient, and A_i is the

8   abundance in pool i. The simplest non-proportional model is the power curve (Harley

9   et al. 2001):

10

11    $$U_i = qA_i^{\beta}$$

12

13   where U_i, q, and A_i are defined as above, and β represents the shape parameter of the

14   power curve. Although a number of non-proportional models have been proposed

15   (Bannerot and Austin 1983; Richards and Schnute 1986), power curves are widely

16   used by fishery agencies (Gaertner and Dreyfus-Leon 2004). If $\beta = 1$, the model

17   reduces to proportional model. Whereas, if $\beta > 1$, U declines faster than A, producing

18   hyperdepletion; conversely, if $\beta < 1$, U declines slower than A, resulting in

19   hyperstability.

20   From the candidate models (i.e., proportional or non-proportional) I decided to

21   examine the relationship between CPUE and abundance. With the intent of modeling

22   catch data in the form of hooking (or not) per unit of effort, according to Gaertner and

23   Dreyfus-Leon (2004), I assumed that a Poisson likelihood function relates the

24   observed CPUE (U_i being a non-negative integer, $U_i = 0, 1, 2, 3, ...$) and predicted

1   CPUE ($\hat{U}_i$ from either the proportional or the power curve model) in pool i as follows:

2

$$L(\theta) = \prod_i \frac{e^{-\hat{U}_i} \hat{U}_i^{U_i}}{U_i!}$$

4

5   where θ is parameter(s) of each candidate model (i.e., q for proportional model, q and

6   β for power curve model), $L(\theta)$ is maximum likelihood, Π is the product symbol, and e

7   is the base of natural logarithms (Agresti 2002). Model parameters were estimated by

8   minimizing:

9

$$\sum_i \left[\hat{U}_i - U_i \log(\hat{U}_i) \right]$$

11

12   The AIC was used as an objective means of model selection. Over-dispersion

13   should be considered if members occur in schools or flocks (Burnham and Anderson

14   2002). I needed to allow for over-dispersion because salmonids show a heterolytic

15   distribution (Nakano 1995a, 1995b). The simplest way to allow for over-dispersion is

16   to perform a quasi-likelihood estimate of the variance inflation factor ($\hat{c}$) from the

17   chi-square goodness-of-fit statistic (χ^2) of the most parameterized model and its

18   degrees of freedom (Burnham and Anderson 2002), where $\hat{c}$ is:

19

$$\hat{c} = \frac{\chi^2}{df}$$

21

22   Using quasi-likelihood theory, and accounting for small-sample bias correction, the

1 conventional AIC criterion is modified as (Burnham and Anderson 2002):

2

3
$$\mathrm{QAIC}c = -\frac{2 \log L(\theta)}{\hat{c}} + 2K + \frac{2K(K+1)}{n-K-1}$$

4

5 where n is the number of observations, and K is the number of parameters (including

6 $\hat{c}$).

7

8 **2-3. Results**

9 The captured red-spotted masu salmon were larger than those observed, whereas

10 there was no significant difference for white-spotted charr (Mann-Whitney U test,

11 masu salmon; $p = 0.006$, charr; $p = 0.135$, Table 2.1). Additionally, for the observed

12 fish, the total length distribution differed between white-spotted charr and red-spotted

13 masu salmon (Mann-Whitney U test, $p = 0.024$).

14 The exploitation rates (total number of fish caught / total abundance) of

15 white-spotted charr and red-spotted masu salmon were 17.9 % (46 / 257) and 10.8 %

16 (90 / 830), respectively (Table 2.1). White-spotted charr was more vulnerable to

17 fishing (G-test, $p = 0.001$). GLM analysis showed a significant positive correlation

18 between CPUE and abundance, and CPUE differed among white-spotted charr and

19 red-spotted masu salmon (abundance: $\chi_1^2 = 32.982$, $p < 0.001$; species: $\chi_1^2 =$

20 13.647, $p < 0.001$). According to the model selection and parameter estimates, the

21 proportional model fitted better than the power curve model for white-spotted charr,

22 whereas for red-spotted masu salmon, the power curve model fitted better (Table 2.2,

23 Fig. 2.2). The shape parameter β was estimated to be < 1.0 (0.5753) for red-spotted

24 masu salmon, suggesting that CPUE declines more slowly than abundance (i.e.,

16

1   hyperstability).

2

3   **2-4. Discussion**

4   This study demonstrated a relationship between hook-and-line fishing and fish

5   abundance using both experimental fishing via random searching and underwater

6   observations in a natural mountain stream. Even though identical angling methods

7   were used in the same habitat, my results suggest that the two species exhibit different

8   exploitation rates and CPUE-abundance relationships.

9   The exploitation rates of white-spotted charr (17.9 %) and red-spotted masu

10   salmon (10.8 %) were substantially high in this experiment. If all caught fish are

11   removed at consistent exploitation rates by proportional fishing efforts to pool areas as

12   my experiments, the abundance of white-spotted charr would decrease to 13.9% of

13   current levels by only 10 anglers, whereas the abundance of red-spotted masu salmon

14   would decrease to 31.9% of current levels. Therefore, in both species, annual

15   exploitation rates should become extremely high.

16   The CPUE-abundance relationship exhibited hyperstability only in red-spotted

17   masu salmon. Usually, hyperstability can result from the tendency for fishing activities

18   to be concentrated in areas where the fish are located when abundance is low, likely

19   because of communication among fishermen and their personal experiences (e.g.,

20   Clark 1985; Johnson and Carpenter 1994). However, hyperstability was exhibited in

21   this study, even though experimental fishing involved random searching by a single

22   fisherman. Thus, actual fishing activities by general recreational fishermen are much

23   more likely to induce hyperstability. According to my results, CPUE would be

24   inappropriate as an index of abundance.

1   Interspecific differences in the relationships between CPUE and abundance may

2   result from differences in species characteristics. Specifically, when nearby fish are

3   caught, the reaction of other fish to the capture event differs among species. My

4   observations indicated that for red-spotted masu salmon, when a fish is caught, the

5   remaining fish are startled and learn to avoid the line and hook. As a result, the

6   abundance of red-spotted masu salmon that can potentially be fished is less than the

7   actual abundance. Ishigaki (1984) suggested that red-spotted masu salmon are more

8   cautious than white-spotted charr. As a consequence, CPUE was asymptotically stable,

9   even though red-spotted masu salmon were more abundant. Whereas, limiting the data

10   set to pools that contained fewer than five red-spotted masu salmon (N = 21), the

11   slope q of the linear model was 0.2196, which is greater than the value for

12   white-spotted charr. As a result, CPUE declines more slowly than abundance (i.e.,

13   hyperstability).

14   Even if the data set is limited to pools that contain less than 25 red-spotted masu

15   salmon (N = 56), corresponding to the maximum abundance of white-spotted charr,

16   the power curve model still provided a better fit of the relationship between CPUE and

17   abundance. Conversely, white-spotted charr CPUE was proportional to abundance,

18   which was likely caused by their boldness, even when nearby fish were caught. In a

19   catch-and-release experiment, Tsuboi and Morita (2004) demonstrated that learning in

20   white-spotted charr was weak (see also Chapter 4 in this dissertation).

21   Body sizes of captured red-spotted masu salmon were larger than those observed

22   red-spotted masu salmon, whereas this pattern was less obvious in white-spotted charr.

23   These results may be related to differences in the home-range preferences of the two

24   salmonids. The dominance hierarchy of red-spotted masu salmon is usually

1 determined linearly with the water column, whereas white-spotted charr often use

2 branched lines in locations with slower currents than those preferred by red-spotted

3 masu salmon (Nakano 1995a). Although I fished in all areas of the study pools,

4 drifting bait within the main current may have resulted in greater vulnerability of

5 larger red-spotted masu salmon. Among the observed fish, white-spotted charr were

6 larger than red-spotted masu salmon, although this size difference likely did not affect

7 the relationship between fishing and abundance. Because I used fishing gear, bait, and

8 methods typical for stream-dwelling salmonids in Japan, it is unlikely that gear

9 competition "(i.e., interspecific difference of fishing selectivity by fishing gear)"

10 occurred between the two species. Additionally, the dietary requirements for

11 white-spotted charr and red-spotted masu salmon are similar (Nakano 1995a).

12 Potential reasons why larger fish were more vulnerable to fishing than smaller fish are

13 discussed in the general discussion (Chapter 6).

14   This study showed that stream-dwelling salmonids were vulnerable to fishing.

15 Therefore, regulations are essential for sustaining fishing resources. In Chapters 3 and

16 4, I investigate the effectiveness of catch and release fishing as a management tool to

17 reduce the impact of fishing on white-spotted charr populations, which were very

18 vulnerable to fishing during the present study.

19

1 **Table 2.1.** Numbers of white-spotted charr (WSC) and red-spotted masu salmon

2 (RMS) classified into three groups (total body length: <100, 100–199, ≥200 mm)

3 captured by hook and line, and numbers observed via snorkeling in 88 pools within

4 Ara Stream.

5

Species	TL[a] (mm)	Captured			Observed		
		< 100	100 – 199	≥ 200	< 100	100 – 199	≥ 200
WSC		0	34	12	15	191	51
RMS		0	72	18	44	682	104

6

7 [a] total length

8

9

10 **Table 2.2.** Summary of analyses using proportional and non-proportional models of

11 the relation between catch per unit effort (number of fish caught / fishing in a pool)

12 and snorkeling-estimated abundance of white-spotted charr (WSC) and red-spotted

13 masu salmon (RMS) in pools within Ara Stream (q = catchability; β = shape

14 parameter; K = number of parameters in the model; –LL = negative log likelihood;

15 QAICc = quasilikelihood Akaike information criterion corrected for small-sample

16 bias; Δ = QAICc difference between the given model and the model with the lowest

17 value with each species).

18

Species	Model	q	β	K	–LL	QAICc	Δ
WSC	Proportional	0.1846	1.0000	2	59.930	146.446	0
	Non-proportional	0.1973	0.9637	3	59.900	148.576	2.130
RMS	Proportional	0.1084	1.0000	2	101.208	173.134	8.101
	Non-proportional	0.3569	0.5753	3	95.034	165.033	0

19

20

1
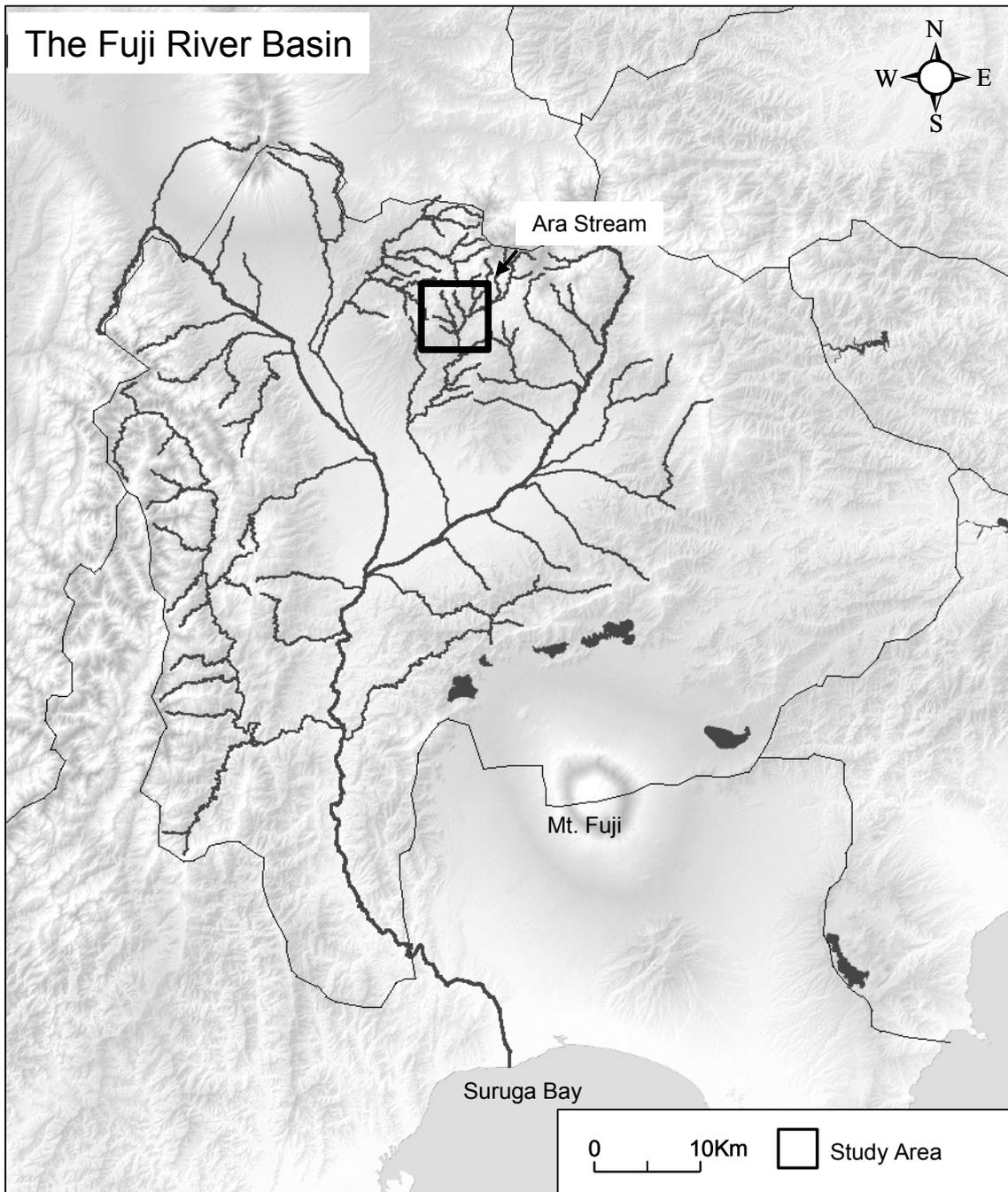
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3   **Fig. 2.1.** Map showing location of study area.

4

5
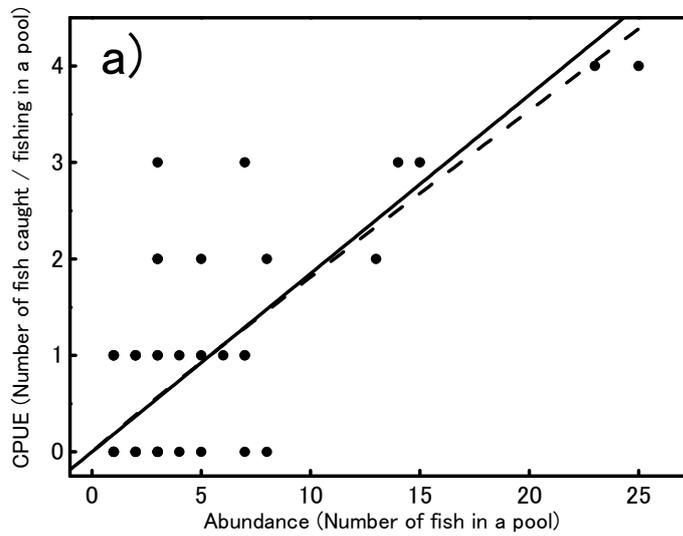
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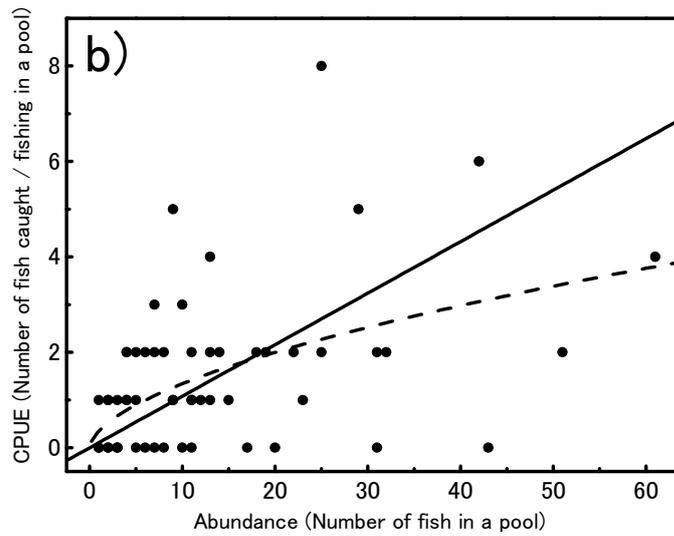
2

3   **Fig. 2.2.** Proportional and non-proportional relationships between hook-and-line catch

4   per unit effort (CPUE; i.e., number of fish caught / fishing in a pool) and

5   snorkeling-estimated abundance for **(a)** white-spotted charr and **(b)** red-spotted masu

6   salmon in pools within Ara Stream. Some points overlap, especially at low

7   white-spotted charr abundances.

8

3

Effects of catch and release fishing on growth, survival, and vulnerability to fishing for white-spotted charr

3-1. Introduction

The ultimate success of catch and release fishing hinges on ensuring high survival rates for released individuals by minimizing injury and mortality (Wydoski 1977; Bartholomew and Bohnsack 2005). However, caught fish suffer from substantial stress (e.g., hook punctures, fighting until landing, and handling). There have been numerous studies which evaluated the effects of catch and release fishing.

Growth

Physiological effects such as increased cortisol levels in muscle were detected associated with catch and release fishing in rainbow trout (Pankhurst and Dedual 1994), Atlantic salmon (*Salmo salar*, Booth et al. 1995), largemouth bass (Gustaveson et al. 1991), and smallmouth bass (*M. dolomieu*, Kieffer et al. 1995). The way in which physical injury or stress from fishing influences feeding and growth in fish is not well understood. Siepker et al. (2006) observed decreased feeding by largemouth bass subsequent to be caught and released, whereas fishing had no effect on the growth rates of rainbow trout (Mason and Hunt 1967), white-spotted charr (Doi et al. 2004), and largemouth bass (Pope and Wilde 2004).

Survival

Fish that have been caught and released might die from lethal injuries or stress.

1 Muoneke and Childress (1994) reviewed mortality rates attribute to catch and release

2 for both freshwater and marine species. They reported that mortality for rainbow trout

3 varied from 1 to 95 % depending on the fishing method, gear, and environmental

4 conditions. In Japan, the mortality rates for hatchery-reared white-spotted charr and

5 masu salmon due to bait fishing in artificial ponds were reported as 5−40 % and

6 5−10 %, respectively (Doi et al. 2004).

7 *Vulnerability of caught and released fish to future fishing*

8   If caught and released fish were to survive, their vulnerability to fishing might

9 decrease through learning (Beukema 1970; Yoneyama et al. 1996). Despite this

10 concern, few studies demonstrated the effect of the experience of being caught on

11 vulnerability to future fishing.

12   The evaluation of growth, survival, and vulnerability to fishing after a single catch

13 and release for wild populations are elementary information to assess the magnitude of

14 catch and release fishing on fish populations. This information can also be a valuation

15 basis to assess the adequacy of previous studies under artificial conditions, especially

16 in related species.

17   In this chapter, I examine the effects of a single catch and release event on growth,

18 survival, and vulnerability to additional fishing for white-spotted charr in four wild

19 streams to evaluate the effectiveness of catch and release fishing as a management tool.

20 White-spotted charr is suitable for catch and release experiment in Hokkaido, because

21 almost all of the fish have a non-anadromous life history in upstream from impassable

22 dams (Morita et al. 2000), where fishing pressure by anglers is negligible.

23

1　**3-2. Materials and methods**

2　*Study area*

3　　　I conducted a field study in four streams: the Mumei (KM) and Katsura streams

4　(KK) of Kame River basin, and the Torii (AT) and Sasuke streams (AS) of Assabu

5　River basin (Table 3.1, Fig. 3.1), in southern Hokkaido. The study areas were located

6　upstream from impassable dams. White-spotted charr have relatively high residency

7　during the summer, which is a non-spawning season (Nakamura et al. 2002, Sato and

8　Watanabe 2004), and therefore movement of individuals downstream and out of the

9　experimental areas was thought to be negligible during the study period. Fish fauna at

10　all of the study areas included only white-spotted charr and fluvial sculpin (*Cuttus*

11　*nozawae*). Fishing pressure, excluding the experimental fishing, was negligible: no

12　fishermen were encountered during the 23 days of fieldwork.

13　*Fishing experiments and measurements*

14　　　Two fishing experiments were conducted at each study area. In the first

15　experiment, conducted between 23 May and 9 June 2000, the fish in the study area

16　divided into two groups: caught fish and control fish (Table 3.2). The entire study area

17　was fished during the daytime using a 4.5-m carbon rod, 3-lb nylon line ($\phi = 0.127$

18　mm), a 1/64 oz. (0.443 g) sinker, and a single-barbed hook (gape width: 7.7 mm), with

19　a wax moth larva (*Galleria mellonella*) as live bait (straight body length: 22.8 ± 1.7

20　mm, mean ± SD). Pliers were used to remove hooks from deep-hooked fish, which

21　were defined as fish hooked in the esophagus or gills. I counted the number of fish

22　that died just after fishing and calculated the mortality rate. I put the caught fish into

23　portable pens (width, 20cm; length, 45cm; depth, 45cm) that were established in the

24　stream. After fishing, the uncaught fish were collected using an electrofisher

1   (Smith-Root, Inc., Vancouver) and a dip net on the same day for use as control fish. I

2   also shocked the caught fish in the portable pens to simulate the conditions

3   experienced by the control fish. The fork length of each captured fish was measured to

4   the nearest 0.5mm. The fish were individually identified using numbered anchor tags

5   (15 mm; Japan Bano'k Co., Ltd., Tokyo) placed at the base of the dorsal fin and

6   immediately released. The dropout of anchor tags was deemed negligible because no

7   fish were caught bearing scarring at the point of attachment.

8   Approximately 50 days later, the recapture experiment (experiment two) was

9   conducted for recapture between 14 July and 5 August (Table 3.2). Following the same

10   methods as in experiment one, fish were captured first through fishing, and then

11   additional fish were collected using an electrofisher. Recaptured fish were again

12   measured for fork length. The marked fish from the first experiment comprised 66.2 –

13   82.0 % of all fish caught, by both fishing and electrofishing, during the second

14   experiment in each area. Therefore, the marking ratios in first experiment were

15   substantially high.

16   *Growth, survival, and vulnerability to fishing*

17   To evaluate the latest growth conditions, the growth increment (*GI*) was

18   calculated individually as:

19

20    $$GI_i = L_i^{\mathrm{r}} - L_i^{\mathrm{m}}$$

21

22   where GI_i is the growth increment between marking and recapture, L_i^{r} is the fork

23   length at recapture (i.e., second experiment), and L_i^{m} is the fork length at marking

1   (i.e., first experiment). There was a negative correlation between GI and L^{m} ($GI =$

2    $13.38 - 0.024 \times L^{\mathrm{m}}$, $r = -0.170$, $p < 0.001$). Therefore, GI_i was standardized according

3   to Yokoyama (1998):

4

5
$$SGI_i = GI_i + b \times (\overline{L}^{\mathrm{m}} - L_i^{\mathrm{m}})$$

6

7   where SGI_i is a standardized growth increment, b is the slope of the above regression

8   (i.e., $b = -0.024$), and $\overline{L}^{\mathrm{m}}$ is the average fork length at marking ($\overline{L}^{\mathrm{m}} = 151$ mm).

9   Two-way ANOVA was used to examine how SGI differed with treatment (caught

10   versus control fish) and among the streams. Additionally, multiple comparisons of SGI

11   among the streams were performed using Bonferroni's inequality (Sokal and Rohlf

12   1995).

13   I compared the recapture rates during the second experiment as an index of

14   survival between caught and control fish using:

15

16
$$P_{\mathrm{rec}}^{\mathrm{F}} = \frac{N_{\mathrm{FF}} + N_{\mathrm{FC}}}{N_{\mathrm{F}}} \quad , \quad P_{\mathrm{rec}}^{\mathrm{C}} = \frac{N_{\mathrm{CF}} + N_{\mathrm{CC}}}{N_{\mathrm{C}}}$$

17

18   where $P_{\mathrm{rec}}^{\mathrm{F}}$ is the recapture rate of fish caught by fishing in the first experiment (i.e.,

19   caught fish), N_{F} is the number of fish caught by fishing in the first experiment, N_{FF} is

20   the number of fish caught by fishing in both the first and second experiments, and N_{FC}

21   is the number of fish caught by fishing in the first experiment and recaptured by

22   electrofishing in the second experiment. $P_{\mathrm{rec}}^{\mathrm{C}}$ is the recapture rate of fish collected by

1 electrofishing in the first experiment (i.e., control fish), N_C is the number of fish

2 collected by electrofishing in the first experiment, N_{CF} is the number of fish collected

3 by electrofishing in the first experiment and recaptured by fishing in the second

4 experiment, and N_{CC} is the number of fish collected by electrofishing in both the first

5 and second experiments. In addition, I estimated the confidence interval for the

6 recapture rates using a binominal distribution according to Sokal and Rohlf (1995).

7   I tested the effects of the experience of being caught on the survival of caught and

8 released fish. Multiple logistic regression analysis was used to examine whether

9 stream specific constant ((Stream A, Stream B, Stream C); KM=(1, 0, 0), KK=(0, 1, 0),

10 AT=(0, 0, 1), AS=(0, 0, 0)), fork length at marking (L^m), and capture experience

11 (caught fish = 1, control fish = 0) were related to the recapture rate (P_{rec}; recaptured by

12 fishing or electrofishing = 1, not recaptured = 0).

13   I compared the probability of being caught by fishing in the second experiment

14 between caught and control fish in the first experiment using:

15

16
$$P_{fish}^F = \frac{N_{FF}}{N_{FF} + N_{FC}} \quad , \quad P_{fish}^C = \frac{N_{CF}}{N_{CF} + N_{CC}}$$

17

18 where P_{fish}^F is the probability of being caught by fishing in the second experiment for

19 the fish caught by fishing in the first experiment (i.e., caught fish), and P_{fish}^C is the

20 probability for the fish collected by electrofishing in the first experiment (i.e., control

21 fish). Multiple logistic regression analysis was used to examine whether stream

22 specific constant ((Stream A, Stream B, Stream C); KM=(1, 0, 0), KK=(0, 1, 0), AT=(0,

1   0, 1), AS=(0, 0, 0)), fork length at recapture (L^r), capture experience (caught fish = 1,

2   control fish = 0) , and standardized growth increment (SGI) were related to the

3   probability of being caught in the second experiment (P_{fish}; recaptured by fishing = 1,

4   recaptured by electrofishing = 0).

5

6   **3-3. Results**

7   The fork lengths of the caught and control fish ranged from 85.0 to 282.5 mm

8   (164.0 ± 41.7mm, mean ± SD) and 80.5 to 275.0 mm (147.4 ± 40.1mm), respectively.

9   Table 3.2 shows sample sizes for each study area in the first and second experiments.

10   In the first experiment, 19 of 282 caught fish died within a few minutes. The hooking

11   mortality was 6.7 % (95 % confidence interval: 4.6−10.5%). All of the dead fish (fork

12   lengths were 110.0 to 211.0 mm, mean =165.3±29.6mm) were hooked deeply in the

13   esophagus or gills.

14   There was no significant difference in the standardized growth increment (SGI)

15   between the caught and control fish, but the stream effect and the interaction between

16   the streams and experience of being caught (caught or control fish) were significant

17   (Table 3.3, Fig. 3.2). With the Bonferroni test, the SGI of caught fish was higher than

18   that of control fish only in the Sasuke stream (AS) ($p = 0.009$, Fig. 3.2). The recapture

19   rate (P_{rec}), as an index of survival, was 78 % (95 % confidence interval: 72−83 %) for

20   caught fish and 74 % (69−79 %) for control fish. There were no significant differences

21   in recapture rates with respect to the experience of being caught or fork length, but

22   there was a significant stream effect (Table 3.4, Fig. 3.3). The probability of being

23   caught in the second experiment (P_{fish}) increased significantly with fork length and

24   SGI, but was not affected by the experience of being caught (Table 3.5, Fig. 3.4).

1

3-4. Discussion

Growth

A single catch and release fishing event had no effect on the growth increment of white-spotted charr (Table 3.3, Fig. 3.2), although some fish might have suffered stress from the experience. This result agrees with previous studies (Mason and Hunt 1967; Doi et al. 2004; Pope and Wilde 2004). Doi et al. (2004) reported that there was no negative effects of the catch and release on the growth and condition factor of both white-spotted charr and masu salmon in experimental ponds. However, in this study, the growth increment was significantly higher in caught fish than in control fish, but only in the Sasuke stream (AS, Fig. 3.2).

Survival

There was no significant difference in the recapture rate with the experience of being caught (Table 3.4, Fig. 3.3), which suggests that caught fish and control fish live similar lives after release. There was also no correlation between the recapture rate and fork length, indicating that small and large fish lead similar lives after release. Studies by Bettoli and Osborne (1998) and Nelson (1998) support these results in striped bass (*Morone saxatilis*). The hooking mortality within a few minutes after capture was 6.7 %. Because the mortality of masu salmon was same level as white-spotted charr in experimental ponds (Doi et al. 2004), the mortality of this chapter could apply to Japanese stream-dwelling salmonids. All of the fish that died shortly after capture were deep-hooked fish, which required more time for hook extraction and suffered greater injury in the process. The reduction in early mortality directly increases the effectiveness of catch and release fishing.

30

Vulnerability to fishing in caught and released fish

The experience of being caught had no effect on the vulnerability to fishing for charr, suggesting that fish that had been caught and released had a similar vulnerability to fishing as same level as control fish (Table 3.5, Fig. 3.4). If fish were to experience capture multi times, they might become less vulnerable through cumulative learning. Alternatively, individual differences in vulnerability may be manifested, with more vulnerable fish being repeatedly caught and released. In the next chapter, I investigated the effects of learning and individuality on vulnerability.

Fork length had a positive correlation with vulnerability to fishing in the second experiment. In other words, larger fish were caught selectively. Potential reasons why larger fish were more vulnerable to fishing than smaller fish are discussed in the general discussion (Chapter 6).

Growth increment was positively correlated with fishing vulnerability in the second experiment. Raat (1985) reported the same tendency in carp. Fast-growing fish should have higher food intake rates compared with slow-growing fish, because growth increments correlate with metabolic rates (Yamamoto et al. 1998). Thus, higher growth rates lead to higher fishing vulnerability.

The experiments in this chapter found no effect of catch and release fishing on growth, survival, and vulnerability to fishing. However, under actual fishing pressure, fish would be caught and released repeatedly. Therefore, in the next chapter, I use a multiple catch and release experiment in a wild stream to investigate individual characteristics related to vulnerability. I discuss the relative effects of learning from the experience of being caught and the individuality of the vulnerability to fishing.

1

Table 3.1. Physical characteristics of each study area. Mumei (KM) and Katsura

streams (KK) of Kame River basin, and Torii (AT) and Sasuke streams (AS) of Assabu

River basin.

Study area	Length of study area (m)	Average width (cm)
KM	700	184
KK	480	365
AT	492	288
AS	675	191

Table 3.2. Dates and sample sizes of each experiment. N_F is the number of fish caught

by fishing (caught fish) and N_C is the number of fish collected by electrofishing

(control fish) in the first experiment. N_{FF} is the number of fish caught by fishing in

both the first and second experiment. N_{FC} is the number of fish caught by fishing in

the first experiment and recaptured by electrofishing in the second experiment. N_{CF} is

the number of fish caught by electrofishing and recaptured by fishing in the second

experiment. N_{CC} is the number of fish caught by electrofishing in both the first and

second experiment.

Study area	First experiment			Second experiment				
	Date	N_F	N_C	Date	N_{FF}	N_{FC}	N_{CF}	N_{CC}
KM	2000/5/23, 24	85	99	2000/7/14, 15	40	30	38	43
KK	2000/6/1, 2	104	122	2000/7/17, 19	39	42	41	50
AT	2000/6/8	35	36	2000/8/5	11	17	16	8
AS	2000/6/9	39	119	2000/8/2, 3	16	10	43	40
Total		263	376		106	99	138	141

32

1

Table 3.3. Two-way ANOVA of the stream effect, experience of being caught in the

first experiment, and their interaction on standardized growth increment.

4

Variable	df	MS	F	P
Stream	3	977.8	37.11	<0.0001
Experience of being caught [a]	1	95.3	3.62	0.0578
Stream×Experience of being caught	3	91.0	3.45	0.0165
Error	475	26.3		

[a] caught or control

7

8

9

Table 3.4. Multiple logistic regression analysis of the stream effect, fork length, and

experience of being caught in the first experiment on recapture rate (P_{rec}) as an index

of survival rate (i.e., recaptured by fishing or electrofishing in the second experiment

= 1, not recaptured = 0).

14

Variable	coefficient	SE	df	P
Stream A [a]	0.800	0.284	1	0.005
Stream B [a]	0.424	0.255	1	0.096
Stream C [a]	0.203	0.324	1	0.531
Fork length	0.00240	0.00250	1	0.336
Experience of being caught [b]	0.0911	0.200	1	0.648
Constant	0.358	0.459	1	0.436

[a] these combinations express four surveyed streams
(Stream A, Stream B, Stream C); KM=(1, 0, 0), KK=(0, 1, 0), AT=(0, 0, 1), AS=(0, 0, 0)

[b] caught or control

20

1

Table 3.5. Multiple logistic regression analysis of the stream effect, fork length in the

second experiment, experience of being caught in the first experiment, and

standardized growth increment on probability of being caught by fishing in the second

experiment (P_{fish}) (i.e., recaptured by fishing in the second experiment = 1, recaptured

by electrofishing = 0).

Variable	coefficient	SE	df	*P*
Stream A [a]	0.8085	0.3089	1	0.0089
Stream B [a]	0.3661	0.2842	1	0.1976
Stream C [a]	-0.3796	0.3890	1	0.3293
Fork length	0.0180	0.0030	1	<0.0001
Experience of being caught [b]	-0.1624	0.2034	1	0.4247
Standardized growth increment	0.0410	0.0191	1	0.0317
Constant	-3.5220	0.6233	1	<0.0001

[a] these combinations express four surveyed streams

(Stream A, Stream B, Stream C); KM=(1, 0, 0), KK=(0, 1, 0), AT=(0, 0, 1), AS=(0, 0, 0)

[b] caught or control

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17
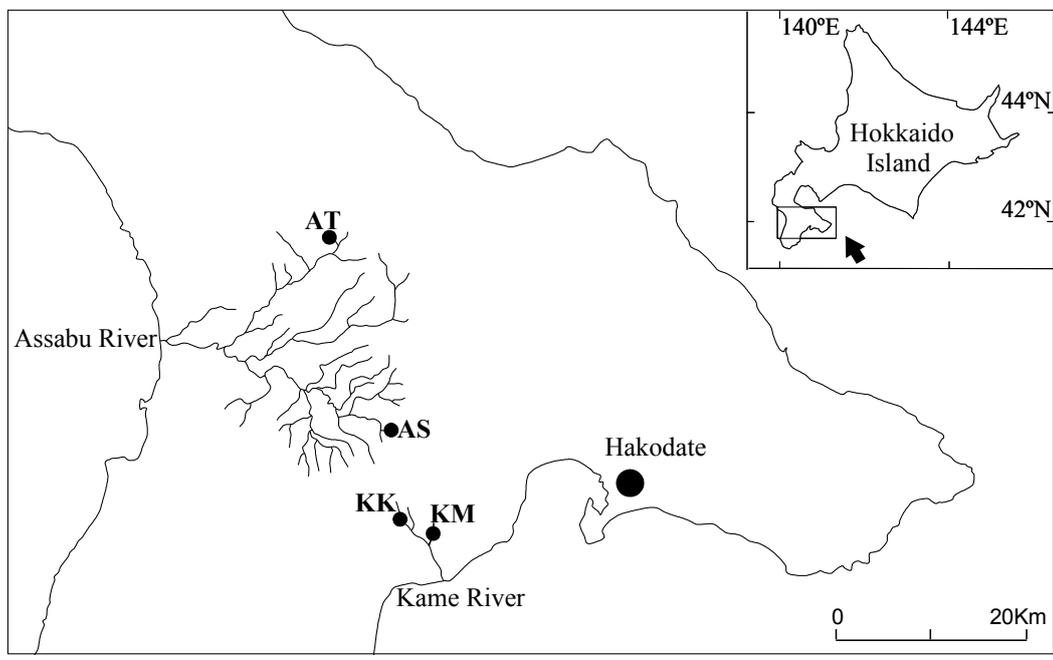
18 **Fig. 3.1.** Map showing location of study areas, Mumei (KM) and Katsura streams

19 (KK) of Kame River basin, and Torii (AT) and Sasuke streams (AS) of Assabu River

20 basin.

21

1
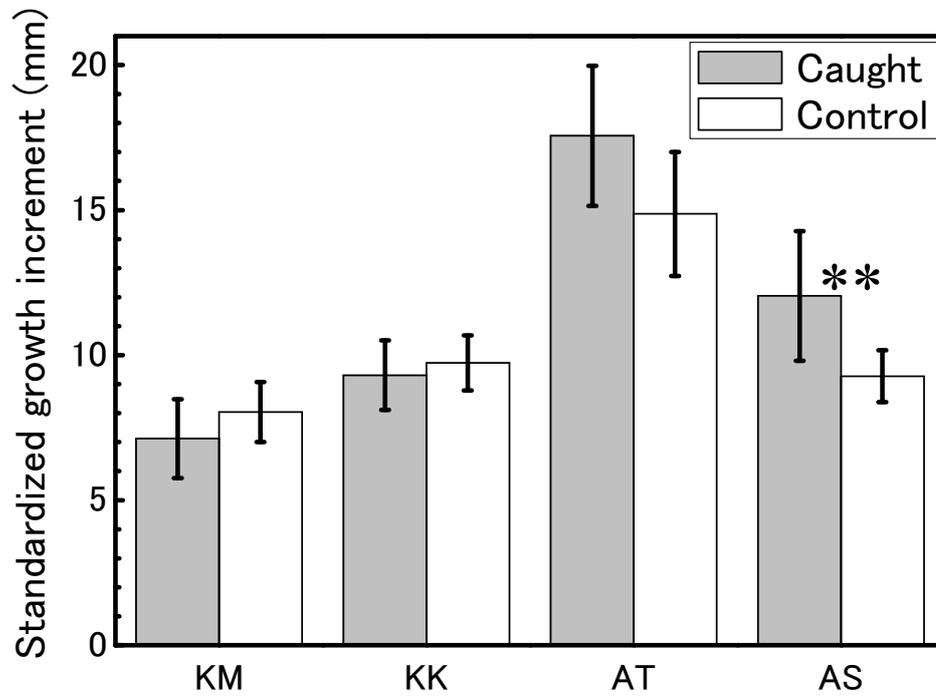
2

3 **Fig. 3.2.** Standardized growth increments of the caught and control white-spotted

4 charr in four streams. Error bars indicate 95% confidence intervals. $^{**}p<0.01$

5

1
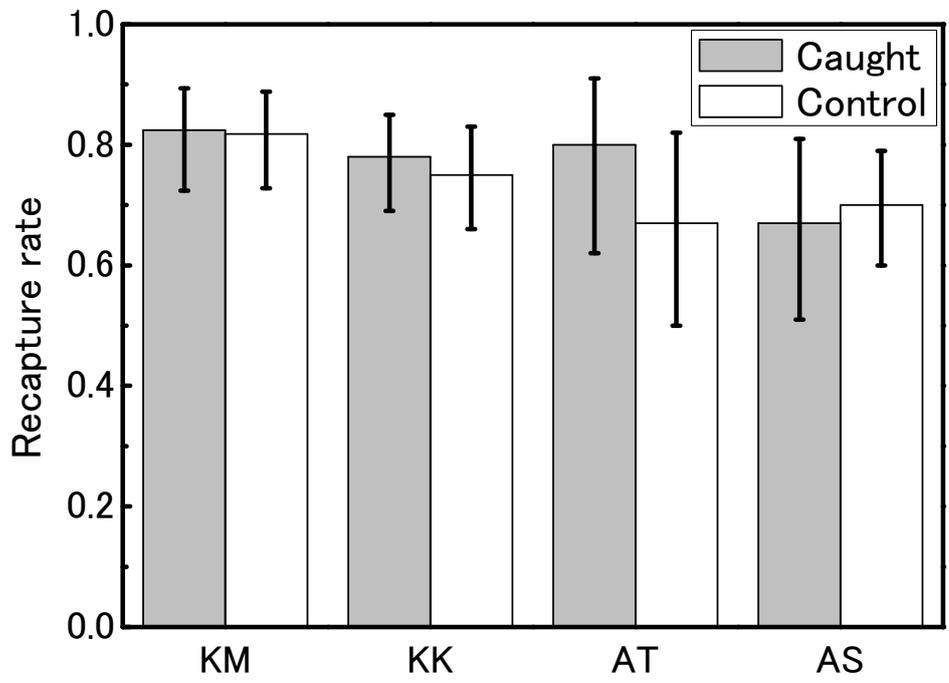
2

3 **Fig. 3.3.** Recapture rates of the caught and control white-spotted charr in four streams.

4 Error bars indicate 95% confidence intervals.

5

1
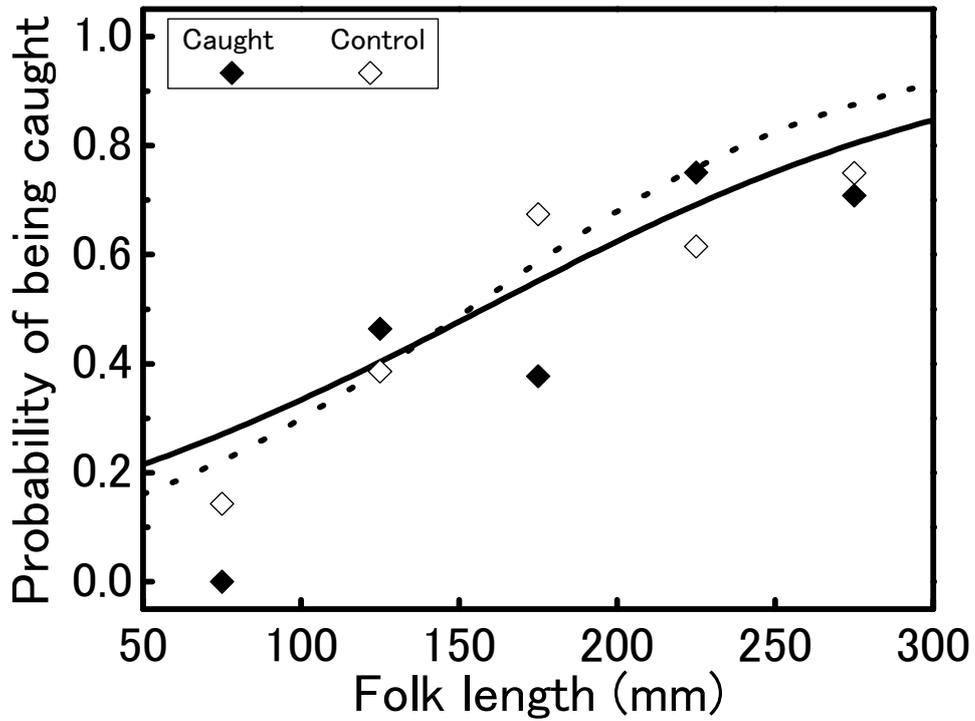
2

3

4   **Fig. 3.4.** Relationship between the fork length and probability of being caught at

5   second experiment of the caught and control white-spotted charr in four streams. Solid

6   and dashed lines indicate caught and control fish, respectively. These plots are

7   calculated each 50mm class, pooled by four streams.

8

4

Selectivity effects on white-spotted charr during catch and release fishing

4-1. Introduction

As almost all fishing is non-random, fisheries scientists have long wondered how fishing is selective with respective to phenotypic variation for a variety of fishing gear (Jennings et al. 2001). In the case of recreational fishing, vulnerability to fishing is related to growth increment (Raat 1985; Tsuboi et al. 2002, see also Chapter 3 in this dissertation), sex (Holtby et al. 1992), age (Mezzera and Largiadèr 2001), body size (e.g., McDonald and Hershey 1989; Yamamoto et al. 2001; Paul et al. 2003), and condition factor (Fernö and Huse 1983).

In addition to phenotypic variation, vulnerability to fishing is also affected by previous capture experiences. Many studies have indicated decreases in vulnerability to fishing during the course of catch and release fishing in experimental ponds (e.g., largemouth bass: Hackney and Linkous 1978; rainbow trout: O'Grady and Hughes 1980; Atlantic cod (*Gadus morhua*): Fernö and Huse, 1983).

Moreover, vulnerability to fishing has another aspect, individuality. Some fish that are caught and released are more catchable than uncaught fish (Yoneyama et al. 1992; 1996). This appears to be counterintuitive, because the learning effect should decrease the probability that the fish would be caught. Yoneyama et al. (1992) proposed inter-individual variation in vulnerability, such that catchable fish would be caught repeatedly. This interpretation is supported by evidence of inter-individual differences in boldness towards predators (Huntingford 1976), feeding behaviour

1   (Iguchi et al. 2001), and habitat utilization (Greenberg and Giller 2001).

2   The probability of being caught could be explained by phenotypic characteristics

3   and vulnerability to fishing, which is determined by capture experience and

4   individuality. These factors would act in concert to affect vulnerability. It is important

5   to evaluate the relative contributions of phenotypic characteristics, learning behaviour,

6   and individuality in order to understand the selectivity of recreational fishing.

7   In this chapter, I investigated the effects of phenotypic variation and experience

8   of being caught on vulnerability to fishing for an individually-marked population of

9   white-spotted charr, through a multiple catch and release experiment.

10

11   **4-2. Materials and methods**

12   *Study area*

13   I carried out a field study in the Sasagoya Stream (Fig. 4.1), a headwater tributary

14   of the Shiodomari River in southern Hokkaido, Japan, from 1 June to 15 August 2001.

15   The Shiodomari River has been designated as a protected freshwater area and is closed

16   year-round to recreational fishing for all species. The study area was 0.9 km in length

17   and 2.7 ± 0.9 m in width. White-spotted charr have a non-anadromous life history in

18   the study area and were located upstream from impassable dams (Morita et al. 2000).

19   White-spotted charr have relatively high residency during the summer, which is a

20   non-spawning season (Nakamura et al. 2002, Sato and Watanabe 2004), and therefore

21   movement of individuals downstream and out of the experimental area was negligible

22   during the study period. Deciduous forest canopy covered approximately 80% of the

23   entire width of the stream. During the study period, the water temperature was

24   8.2–16.4 °C (mean ± SD, 13.0 ± 1.6 °C), as measured with a data logger (Onset

1 Computer Co., MA) placed within the preferred feeding range of white-spotted charr

2 (Takami et al. 1997).

3 *Fishing experiment and measurements*

4   Before fishing, I identified individual white-spotted charr in the study area. Fish

5 were collected using an electrofisher (Smith-Root, Inc., Vancouver) and a dip net,

6 making one pass per day from 22 to 24 May (Table 4.1). The fork length of each

7 captured fish was measured to the nearest 0.5 mm. Fish were individually identified

8 using numbered anchor tags (15 mm; Japan Bano'k, Co., Ltd., Tokyo) placed at the

9 base of the dorsal fin and immediately released at the capture site. The dropout rate for

10 anchor tags was negligible, given that no fish were found with scarring that would

11 have appeared after dropout. The recapture rate of tagged white-spotted charr after 50

12 days did not differ between fork length classes, which ranged from 80.5 to 282.5 mm

13 (Tsuboi et al. 2002, see also Chapter 3 in this dissertation), indicating a similar level of

14 tagging stress throughout the fork length range. Therefore, a total of 415 fish larger

15 than 90 mm were individually identified in this study.

16   Eleven fishing episodes were conducted from 1 June to 11 August 2001 (Table

17 4.1). I fished the entire study area during daylight on each day, using a 4.5-m carbon

18 rod, 3-lb nylon line ($\phi = 0.127$ mm), a 1/64 oz. (0.443 g) sinker, and a single-barbed

19 hook, with a wax moth larva as live bait (straight body length: 22.8 ± 1.7 mm). The

20 hook size was 13.4 mm in linear measure, 7.7 mm in gape width, 0.54 mm in shank

21 diameter, and 40.9 mg in weight. It was made from carbon steel (carbon content,

22 0.8%) and was thinly nickel-plated by electrolysis. Caught fish were removed from the

23 hook, the tag number was checked, and they were immediately released at the capture

24 site. Previous studies have indicated that cutting the line rather than removing the

1   hook reduced post-release mortality for deep-hooked fish (e.g., Schill 1996; Schisler

2   and Bergersen 1996; Tsuboi et al. 2006, see also Chapter 5 in this dissertation).

3   Therefore, when fish were deep-hooked fish, the line was cut near the hook. Only one

4   fish (0.14%) died before release.

5   In total, 366 fish were recaptured during the experiment, in either the 11th fishing

6   or 2nd electrofishing episode (recapture rate, 88.2 %; Table 4.1). For all recaptured

7   fish, I measured fork length (to the nearest 0.5 mm), weighed somatic weight (g), sex,

8   and aged (otolith analysis; Yamamoto et al. 1992). To compare fatness between

9   individuals of different body sizes, I used a relative condition factor (*CF*) according to

10   Iguchi et al. (2001):

11

$$CF_i = \frac{W_i^{\mathrm{o}}}{W_i^{\mathrm{e}}}$$

12

13

14   where W_i^{o} is the observed somatic weight, and W_i^{e} is the expected somatic weight.

15   W_i^{e} was obtained from a nonlinear regression as

16

$$W_i^{\mathrm{e}} = -1.32 + 1.81 \times 10^{-5} \times L_i^{\mathrm{r}\,2.85}$$

17

18

19   where L_i^{r} is the fork length at recapture. To evaluate the latest growth conditions, the

20   standardized growth increment (*SGI*) was calculated as per Chapter 3:

21

$$SGI_i = GI_i + b \times (\overline{L}^{\mathrm{m}} - L_i^{\mathrm{m}})$$

22

1

2   where $b = -0.062$ and $\overline{L}^{\mathrm{m}} = 155$ mm.

3   *Statistical analyses*

4   The statistical analyses included only fish that were recaptured at the end of the

5   fishing experiment ($n = 366$) in the statistical analyses. Initially, I tested whether the

6   variance of the frequency distribution of captures for each fish during the 11 fishing

7   episodes was different from a Poisson distribution, using a two-tailed χ^2 test (Sokal

8   and Rohlf 1995). If the variance is significantly smaller than the theoretical case, the

9   frequency distribution of the number of captures concentrates the average. Thus, a

10   learning effect in response to hooking would exist, because all fish are expected to be

11   vulnerable until they reach the average number of captures, at which point they would

12   become less vulnerable. A larger number of captures would indicate individuality in

13   the vulnerability to fishing, because vulnerable fish would be caught repeatedly.

14   I analyzed the selectivity effects on fish during multiple catch and release fishing

15   episodes. First, I examined the relationship between capture experience (i.e., the

16   number of times caught) and phenotypic variation. Simple regression analyses were

17   used to examine whether fork length, age, standardized growth increment, and

18   condition factor were related to capture experience. Analysis of variance (ANOVA)

19   was used to examine how this experience differed between the sexes.

20   Second, I tested the effects of the capture experience on the vulnerability to

21   fishing during the 11th fishing episode. Logistic regression analysis was used to

22   examine whether capture experience, the time since last capture, the number of hooks

23   in the body due to cutting of lines, fork length, standardized growth increment,

24   condition factor, age, and sex were related to the probability of being taken by an

1   angler. To identify subsets of significant variables, I used the Akaike information

2   criterion (AIC). Of the possible 256 models, the logistic regression model with the

3   lowest AIC among the all-possible 256 models was selected as the best model.

4

5   **4-3. Results**

6   The fork lengths of the fish ranged from 96 to 311 mm, and the ages ranged from 1

7   to 7 years old. The experience of being caught varied from 0 to 7 times per fish for 11

8   fishing episodes (Fig. 4.2). On average, each fish was caught 2.15 ± 1.32 times (mean

9    $\pm$ SD). The variance was significantly smaller than the theoretical variance (χ^2 test: df

10   $= 365$, $\chi^2 = 295.14$, $p < 0.01$), suggesting that the frequency distribution of the number

11   of times caught concentrates the average. Whereas, the number of fish with no capture

12   experience was 41 of 366 recaptured fish (11.2%).

13   Capture experience increased significantly with fork length and age, but not with

14   the standardized growth increment or condition factor (Fig. 4.3a-d; fork length: $r =$

15   0.418, $p < 0.001$; age: $r = 0.372$, $p < 0.001$; standardized growth increment: $r = -0.019$,

16   $p = 0.72$; condition factor: $r = -0.053$, $p = 0.31$). Partial correlation analysis showed a

17   significant positive correlation between fork length and capture experience (fork

18   length: $r = 0.212$), but no significant correlation was found between age and

19   experience ($r = 0.052$, $p > 0.05$). This indicates that larger fish, regardless of age, were

20   vulnerable to fishing. Males had a significantly greater capture experience than

21   females (Fig. 4.3e; $F_{1,364} = 4.259$, $p = 0.04$). As neither the average nor the variance of

22   fork length differed between the sexes (average: $F_{1,364} = 0.003$, $p = 0.96$; variance:

23   $F_{188,176} = 0.892$, $p = 0.41$), there was a sex-related difference in capture experience, in

24   addition to the fork length effect.

1   Capture experience differed significantly between fish recaptured by fishing (2.14

2   ± 0.25 times, mean ± SD) and by electrofishing (1.77 ± 0.13 times) during the 11th

3   fishing episode (ANOVA, $F_{1,364} = 7.34$, $p = 0.007$). The logistic regression model that

4   included fork length and capture experience had the lowest AIC among the 256

5   possible models. Therefore, fork length and capture experience were identified as the

6   best predictors of the probability of being caught during the 11th episode. These

7   results indicate that vulnerability to fishing related to capture experience, in addition

8   to fork length. Using the best logistic regression model, I predicted the relationship

9   between fork length and the probability of being caught in the 11th fishing episode,

10   for different levels of experience of being caught during episodes 1st through 10th

11   (Fig. 4.4). Large fish and the fish had a lot of experience of being caught were more

12   vulnerable to fishing.

13

14   **4-4. Discussion**

15   *Selectivity due to phenotypic variation*

16   Many studies have documented that larger fish are more vulnerable to fishing than

17   smaller fish (e.g. white-spotted charr: Yamamoto et al. 2001; Tsuboi et al. 2002, see also

18   Chapter 3 in this dissertation; cutthroat trout, bull trout (*S. confluentus*), and brook trout:

19   Paul et al. 2003). My results are consistent with the findings of the previous studies (Fig.

20   4.3a). Potential reasons why larger fish were more vulnerable to fishing than smaller

21   fish are discussed in the general discussion (Chapter 6).

22   Males were more likely to be caught by anglers than females (Fig. 4.3e), although

23   there was no significant difference in fork length between the sexes. Recent studies have

24   identified behavioral differences between the sexes in stream-dwelling salmonids

1   (Johnsson and Åkerman 1998; Johnsson et al. 2001). These studies of young rainbow

2   trout and brown trout (*S. trutta*) reported that males are more aggressive than females in

3   intersexual contests. Therefore, the higher activity of males might cause the male-biased

4   vulnerability to fishing. Morphological differences between the sexes might also

5   contribute to the male-biased vulnerability to fishing. Most salmonid species have

6   sexual dimorphism in jaw shape at maturity: males have longer jaws than females (e.g.,

7   Reyes-Gavilán et al. 1997). As most of the fish caught in this study had attained the

8   threshold size for maturity (Morita and Morita 2002), sexual dimorphism might have

9   relaxed the physical limits of mouth size for males.

10   In contradiction to the findings reported in Chapter 3 in this dissertation, there was

11   no correlation between growth increment and vulnerability to fishing. Fast-growing fish

12   were potentially more vulnerable to fishing than slow-growing fish (Tsuboi et al. 2002,

13   see also Chapter 3 in this dissertation). However, experiencing several captures might

14   cause a decrease in growth increment for fast-growing fish, owing to decreased foraging

15   frequency caused by handling stress. As a result, the inter-individual differences of

16   standardized growth increments would be smoothed for all fish.

17   *Selectivity due to capture experience*

18   Both learning effects and individuality would coexist in white-spotted charr

19   through the fishing experiments. The variance of the frequency distribution of capture

20   experience was significantly smaller than the theoretical one, suggesting the existence

21   of a learning effect of hook. In fact, it appeared that the number of white-spotted charr

22   approaching the bait but not biting increased during the course of the fishing

23   experiment. Whereas, fish with greater capture experience were more vulnerable to

24   fishing, even after adjusting for fork length (Fig. 4.4). This result is consistent with the

1   results of Yoneyama et al. (1992) but not with those of several other studies (Beukema

2   1970; Raat 1985). Yoneyama et al. (1992) argued that vulnerability to fishing was

3   related to inter-individual behavioral differences aside from body size. In Chapter 3,

4   an effect of capture experience was not detected between two fishing episodes,

5   possibly because the intervals of episodes were substantially long (i.e. 50days) in each

6   river.

7   The magnitude of the learning effect caused by capture experience would depend

8   on not only species but also fishing pressure and the level of handling stress. Rainbow

9   trout have polymodal nociceptors (i.e., pain receptors) (Sneddon et al. 2003), physical

10   stimulation from the hook is considered the main factor responsible for the learning

11   effect (Beukema 1970; Fernö and Huse 1983). Generally, increases in stimulation are

12   positively associated with the learning (Homans 1974). Although in my fishing

13   experiment the handling stress was expected to be small because hooking mortality

14   was small (0.13%), the result of χ^2 test of the frequency distribution of capture

15   experience for individual fish suggested the existence of a learning effect. Under

16   actual fishing conditions, handling stress could be greater, depending on the angler's

17   skill. Therefore, the learning effect might be substantial under such conditions.

18   It is possible to explain vulnerability based on the relative magnitudes of

19   individuality and the learning effect (Fig. 4.5). If inter-individual differences in

20   vulnerability to fishing were of greater magnitude than the learning effect, individual

21   fish would be caught repeatedly (Fig. 4.5a). This is the case for tilapia (Yoneyama et

22   al. 1992) and white-spotted charr (Tsuboi et al. 2002, see also Chapter 3). Conversely,

23   if the learning effect were greater than individuality, fish would not be repeatedly

24   caught (Fig. 4.5b). This is the case for carp (Beukema 1970; Raat 1985). For

1   red-spotted masu salmon, learning effect would be greater than individuality, likely

2   because when a fish is caught, the remaining fish are startled and learn to avoid the

3   line and hook without fishing experiences (Chapter 2).

4   My understanding of the changes in vulnerability to fishing for white-spotted charr

5   during the study period is summarized in Fig. 4.5c. Vulnerability to fishing decreased

6   with capture experience; however, the hierarchy of vulnerability did not change

7   because individuality was greater than the learning effect.

8   Caught fish would be valuable to anglers because these fish would be caught

9   repeatedly if catch and release program were successful. Therefore, hooking mortality

10   must be minimized in order to increase the population of caught fish. One promising

11   approach to reducing hooking mortality is to cut the fishing line when a fish is deeply

12   hooked. In the next chapter, I follow the fate of deep-hooked fish after the line has

13   been cut, via a multiple catch and release experiment identical to that in this chapter.

1

Table 4.1. Summary of sample sizes and water temperature for each episode.

3

Date	Purpose	Sampling technique	Total number of marked fish captured	Deep-hooked fish [c]	Water temperature at noon (^{o}C)
2001/5/22-24	Mark	Electrofishing 1	415		10.3
2001/6/1	Catch and Release	Angling 1	95 (9) [a]	5 (1) [a]	11.7
2001/6/8	Catch and Release	Angling 2	72 (9)	5 (0)	12.3
2001/6/15	Catch and Release	Angling 3	66 (2)	13 (0)	11.1
2001/6/22	Catch and Release	Angling 4	61 (5)	4 (0)	10.6
2001/6/29	Catch and Release	Angling 5	69 (6)	15 (2)	15.0
2001/7/6	Catch and Release	Angling 6	84 (7)	12 (1)	14.7
2001/7/13	Catch and Release	Angling 7	69 (0)	7 (0)	14.7
2001/7/20	Catch and Release	Angling 8	81 (8)	7 (0)	12.8
2001/7/27	Catch and Release	Angling 9	72 (2)	8 (1)	14.5
2001/8/3	Catch and Release	Angling 10	66 (2)	12 (1)	13.3
2001/8/10-11	Recapture	Angling 11	103 [b]		14.4
2001/8/13-15	Recapture	Electrofishing 2	263 [b]		14.2

4

5   [a] The numbers of fish that were not recaptured in the 11th fishing or the 2nd

6   electrofishing episodes are shown in parentheses.

7   [b] These fish were not released.

8   [c] Deep-hooked fish were released by cutting the line.

9

1
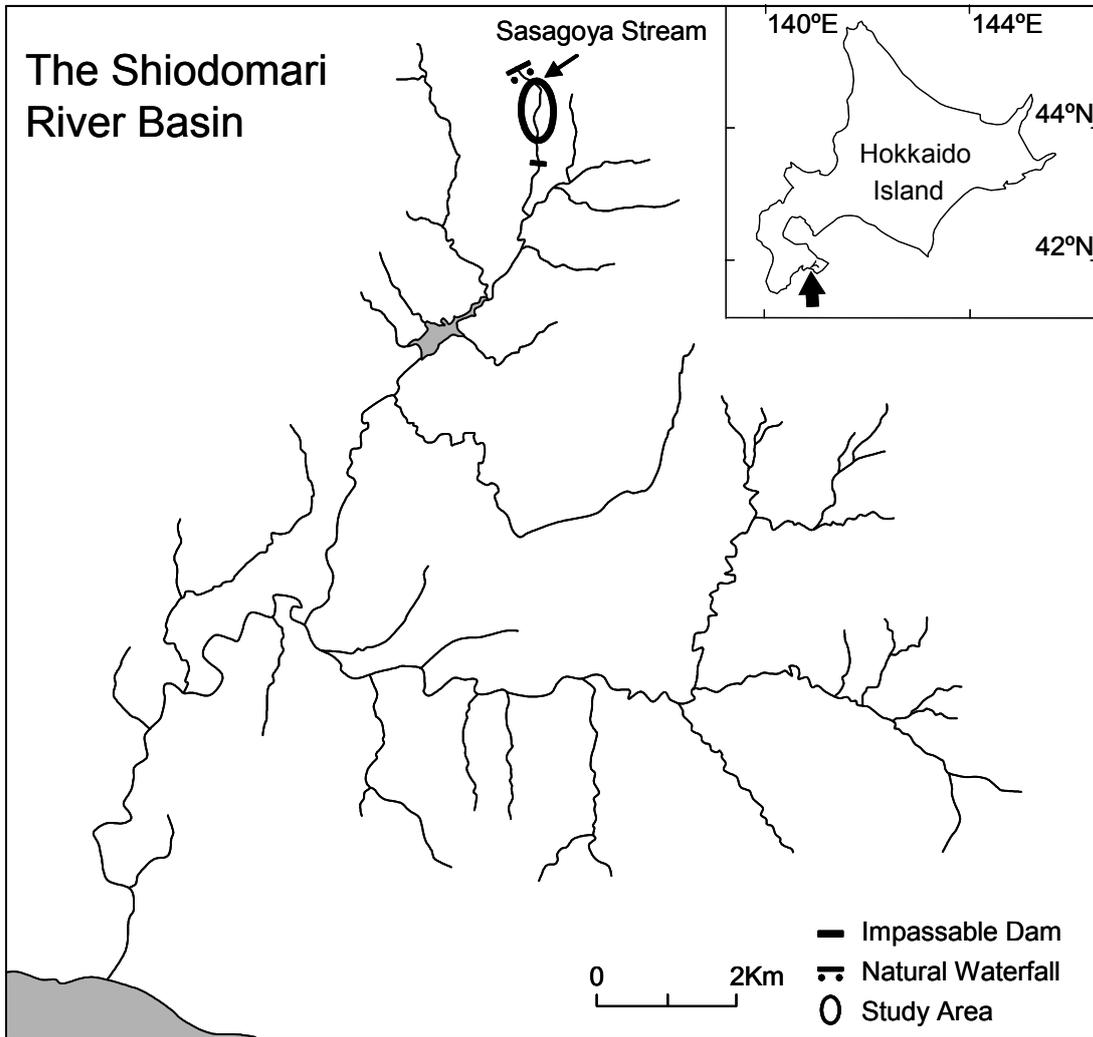
Fig. 4.1. Map showing location of study area.

1
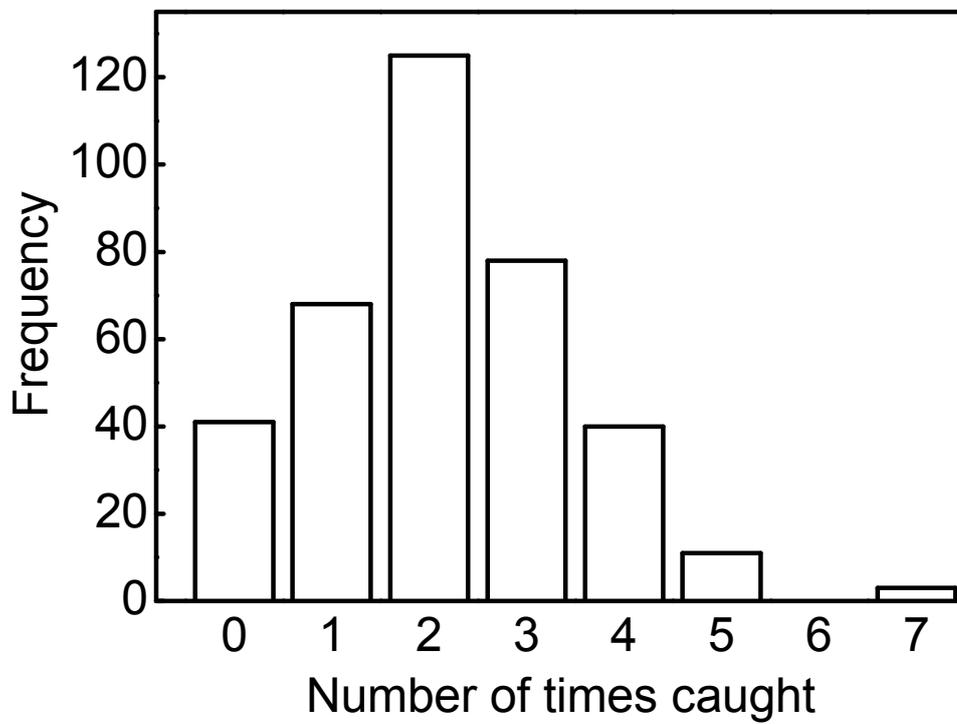
2

3 **Fig. 4.2.** Frequency distribution of experience of being caught in white-spotted charr

4 for 11 fishing episodes.

5

1
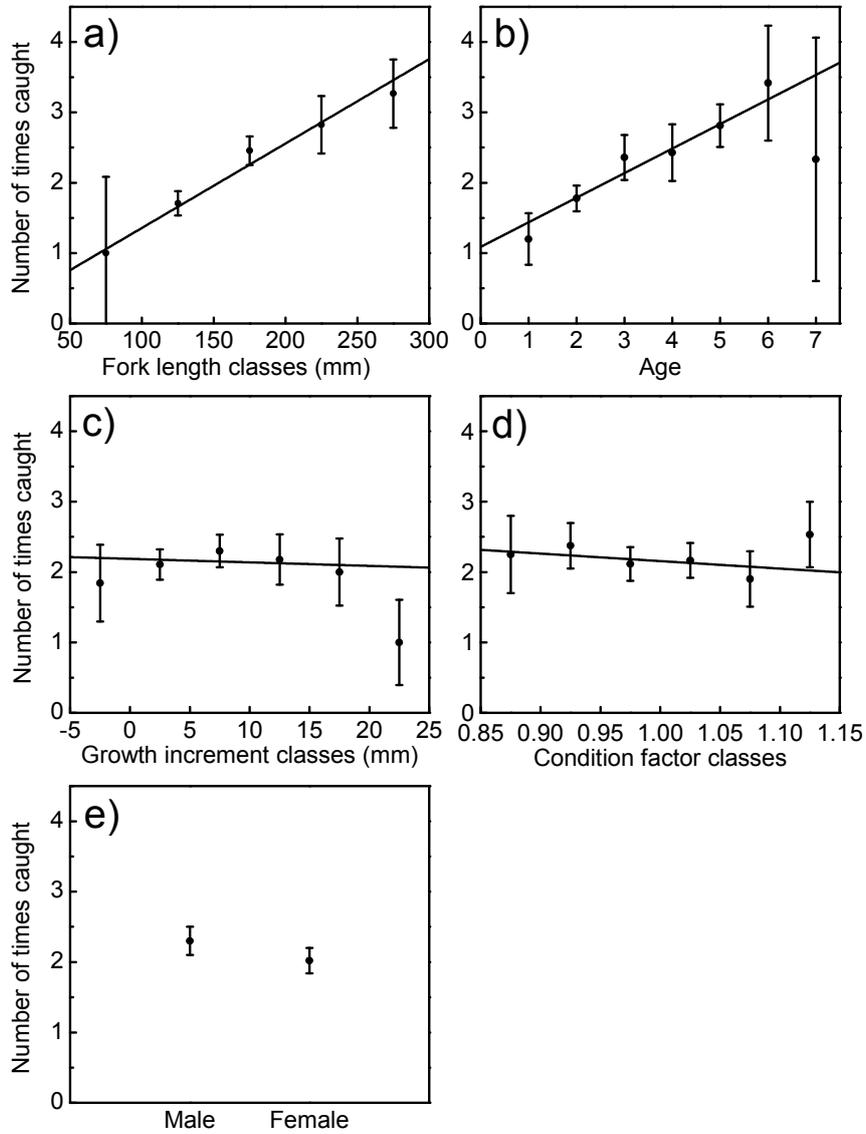
2

3   **Fig. 4.3.** The relationships between the experience of being caught and a) average fork

4   length, b) age, c) standardized growth increment, d) condition factor, and e) sex. The

5   error bars indicate 95% confidence intervals.

6

52

1
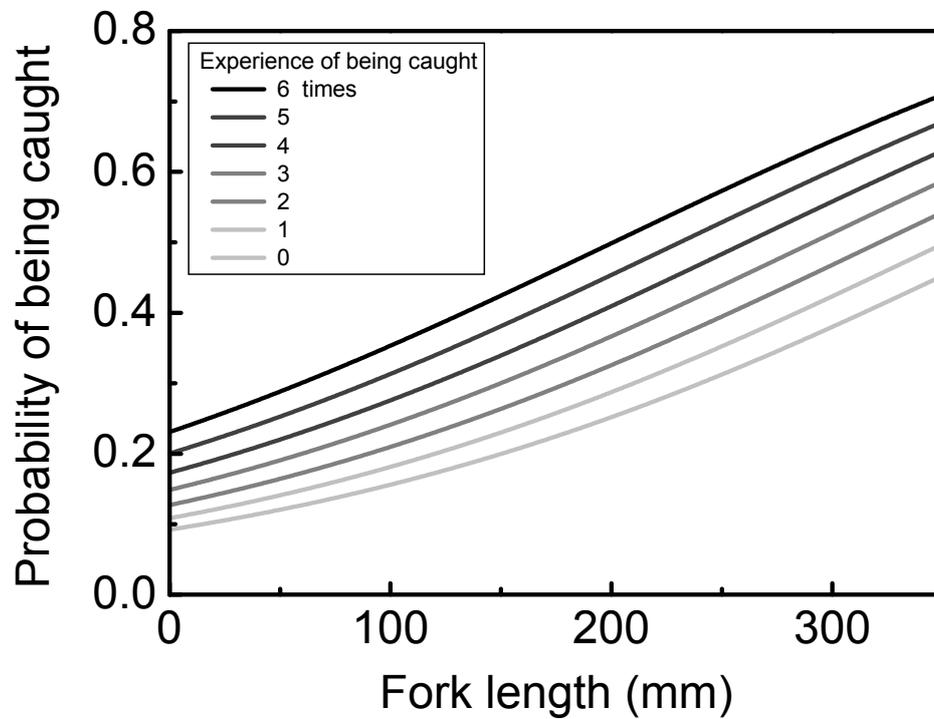
2

3 **Fig. 4.4.** Relationship between fork length and the probability of being caught in the

4 11th fishing episode with different experience of being caught during episodes 1st to

5 10th obtained from the best logistic regression model.

1
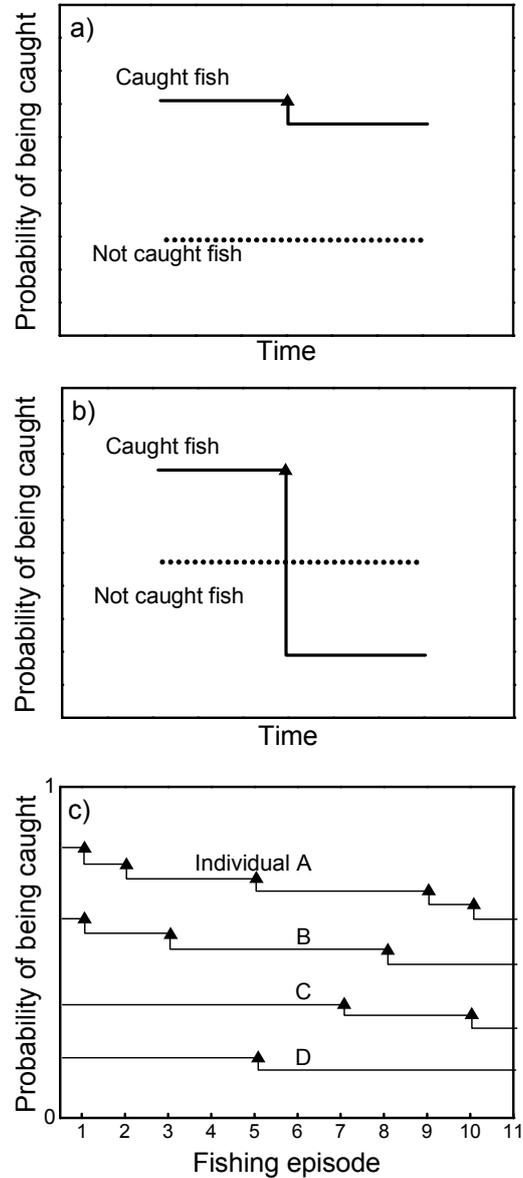
3 **Fig. 4.5.** Graphic model explaining the changes in vulnerability to fishing a) if the

4 learning effect is smaller than the individual variation, and b) if the learning effect is

5 greater than the individual variation. c) Schema explaining the intergradation of the

6 probability of being caught with increasing capture experience of it in this study. ▲

7 Solid triangles indicate the experience of being caught.

8

54

1   5

2   Fate of deep-hooked white-spotted charr with line-cut release

3   during catch and release fishing

4

5   **5-1. Introduction**

6   The successful catch and release of fish can help sustain populations and

7   maintain acceptable levels of catch per unit effort (Wydoski 1977). However, many

8   studies of hooking mortality (reviewed in Taylor and White 1992; Muoneke and

9   Childress 1994; Cooke and Suski 2004; Bartholomew and Bohnsack 2005) indicate

10   that the mortality of deep-hooked fish is very high because of massive bleeding and

11   fatal injuries during hook removal.

12   To avoid swallowing of the hook into the esophagus, Cooke and Suski (2004)

13   recommended the use of circle hooks, which rarely penetrated the esophagus

14   compared with the commonly used J hooks. A new hook, the Shelton self-releasing

15   hook, has recently been introduced. Reportedly, these hooks can be removed easily

16   regardless of the penetration site, and thus hooking mortality is negligible with these

17   hooks (Jenkins, 2003). Nevertheless, both circle hooks and Shelton self-releasing

18   hooks are still uncommon in recreational fishing.

19   Presently, cutting the line is more effective than removing the hook for reducing

20   post-release mortality of deep-hooked fish (e.g., Mason and Hunt 1967; Schisler and

21   Bergersen 1996; Schill 1996). Furthermore, any hooks that remain after a line is cut

22   are likely to be evacuated by salmonids (e.g., Hulbert and Engstrom-Heg 1980;

1 Schisler and Bergersen 1996; Doi et al. 2005).

2 Most studies investigating long-term hooking mortality and the evacuation of

3 hooks after catch and release fishing have been conducted in pens. This artificial

4 habitat is vastly different from the natural environment (e.g., food, density, predation

5 pressure, substrate, velocity), making it difficult to evaluate the effectiveness of

6 cutting the line under actual fishing conditions. Specifically, cutting the line might

7 hinder foraging by deep-hooked fish in the natural environment, because remnant

8 hooks might interrupt the passage of natural prey through the esophagus, but not

9 hinder the passage of pellet used in mixed feed.

10 In this study, I examined the impacts of remnant hooks on survival and estimated

11 the time required for hook corrosion and evacuation, in a multiple catch and release

12 experiment, identical to that in Chapter 4.

13

14 **5-2. Materials and methods**

15 The data used in this study originated from Tsuboi and Morita (2004, see also

16 Chapter 4). Deep-hooked fish that were released by cutting the line were X-rayed

17 (Sofron, Tokyo) and autopsied to locate the hook (lying or embedded), to check the

18 degree of corrosion, and to determine whether the hook had been evacuated. When

19 only one hook remained in a fish that had been released by cutting the line twice, I

20 assumed that the older hook had been evacuated. The probabilities of hooks remaining

21 (P_i^{rem}) and being uncorroded (P_i^{unc}) in a gut at recapture were calculated for each

22 fishing episode:

23

$$P_i^{\text{rem}} = \frac{N_i^{\text{rem}}}{N_i^{\text{cut}}}$$

2

3   where i is each fishing episode, N_i^{rem} is the number of hooks remaining at recapture

4   and N_i^{cut} is the number of fish that were deep-hooked and released by cutting the line

5   in each fishing episode. P_i^{unc} was also calculated:

6

$$P_i^{\text{unc}} = \frac{N_i^{\text{unc}}}{N_i^{\text{cut}}}$$

8

9   where N_i^{unc} is the number of hooks that were uncorroded at recapture in each fishing

10   episode. The hebdomadal probabilities of hooks remaining and being uncorroded were

11   back-calculated from the first day of recapture to each fishing episode. For example,

12   the probability for the 10th fishing episode corresponds to that of 7 days after cutting

13   the line (Table 5.1).

14   *Statistical analyses*

15   I examined the degree of the hook penetration (deep or superficial) with regard to

16   sex, which was verified by dissection (*G*-test) and fork length (ANOVA). A logistic

17   regression was used to model the probability of hooks remaining and being

18   uncorroded at a given time after the line had been cut. The probability of hooks

19   remaining, $\hat{P}^{\text{rem}}$, equalled

20

$$\hat{P}^{\text{rem}} = \frac{\exp(a+bt)}{1+\exp(a+bt)}$$

22

1   where t is the number of days after cutting the line, and a and b are parameters. The

2   probability of hooks being uncorroded, $\hat{P}^{unc}$, was treated similarly. The model

3   parameters were estimated using the maximum likelihood method. Here, $\hat{P}^{rem}$ and

4    $\hat{P}^{unc}$ are always decreasing functions of time, t. The times at the 50% probability of

5   hooks remaining and of hooks being uncorroded indicate the estimated time until hook

6   evacuation and the starting time for hook corrosion, respectively (c.f., Metcalf et al.

7   2003). The estimated times can be calculated as $-a / b$ from the logistic regression

8   (Metcalf et al. 2003).

9

10   **5-3. Results**

11   The fork length of the marked fish ranged from 96 to 311 mm. From a total of

12   735 captures (1.77 times per fish, on average), 88 captures were deeply hooked; all of

13   the deep-hooked fish were alive immediately just after fishing and were released by

14   cutting the line (Table 5.1). Eleven fish were deep-hooked twice and released in this

15   manner. Only one fish died before release; it had not been deeply hooked, but suffered

16   heavy bleeding. Neither the fork length nor sex ratio differed between fish subject to

17   cut-line release and those that were not (fork length: ANOVA, $F_{1,\,733} = 0.824$, $p =$

18   0.364; sex: G-test, $p = 0.329$).

19   In this multiple catch and release experiment, 68.8 % (53 / 77) of the

20   deep-hooked fish were caught again after cut-line release. After the experiment, 93.5%

21   (72 / 77) of the deep-hooked fish were recaptured. This recapture rate was as high as

22   that of the fish had more than one experience of being caught and released normally

23   (92.5%, 245 / 265; G-test, $p = 0.952$). The fish with two imbedded hooks were

24   recaptured at a rate almost as high as the fish with one imbedded hook (10 / 11 and 62

1   / 66; *G*-test, *p* = 0.945). Of the 82 hooks in the 72 deep-hooked and cut-line released

2   fish that were sampled, 27 (32.9 %) hooks had been evacuated, 35 hooks were

3   embedded in the esophagus (Fig. 5.1A–C), one hook was embedded in the stomach

4   (Fig. 5.1D), and 19 hooks lay in the stomach (Fig. 5.1B). Eight hooks were fractured

5   in the esophagus or stomach (Fig. 5.1D, E). The probability of hooks being

6   uncorroded, P_i^{unc}, at 7 days after cutting the line was 91 %, whereas it was 0 % at 63

7   days (Fig. 5.2). The probability of hooks remaining, P_i^{rem}, was also 0 % a 70 days

8   after cutting the line. Logistic regression analyses showed that the probability of a

9   hook remaining and being uncorroded decreased with time ($\hat{P}^{\mathrm{rem}}$: *a* = 2.666, *b* =

10 −0.050, *p* = 0.001; $\hat{P}^{\mathrm{unc}}$: *a* = 1.765, *b* = −0.080, *p* < 0.001; Fig. 5.2). The estimated

11 time before a remaining hook started to corrode was 22.1 days after cutting the line,

12 and the estimated time for hook evacuation was 53.3 days after cutting the line.

13

14 **5-4. Discussion**

15   A total of 77 fish were deep-hooked and released by cutting the line, of which 11

16 were twice hooked and released by line cutting. After cut-line release, 68.8 % of the

17 deep-hooked fish were caught again and 93.5 % were recaptured at the end of the

18 experiment, indicating that the survival rates of fish released by cutting the line are

19 sufficiently high to be encouraging in a natural environment. Furthermore, the hooks

20 remaining in the gut corroded and evacuated with time.

21   The incidence of deep hooking was not related to fork length or sex. However,

22 since larger fish were more likely to be caught repeatedly (Tsuboi and Morita 2004,

23 see also Chapter 4 in this dissertation), larger fish tended to be deep hooked more

1 often than smaller fish. Some hooks were corroded or fractured in the gut. Hulbert and

2 Engstrom-Heg (1980) argued that gastric digestion helps to evacuate deep hooks.

3 However, a retained hook would have an adverse affect on foraging and digestion.

4 Under artificial conditions, cut-line fish grow less than fish treated in other ways

5 (Jenkins 2003), whereas there was no negative effect on growth (Mason and Hunt

6 1967; Hulbert and Engstrom-Heg 1980). In this study, a retained hook might have

7 prevented foraging and the digestion of irregularly shaped natural food.

8   The estimated time required for hook evacuation was 53 days, although the time

9 highly dispersed. I compared the probability of hook evacuation between previous

10 studies and this study (Table 5.2; Mason and Hunt 1967; Hulbert and Engstrom-Heg

11 1980; Schisler and Bergersen 1996; Doi et al. 2005). Since evacuation speed in this

12 study was obviously faster than reported in Mason and Hunt (1967), Hulbert and

13 Engstrom-Heg (1980), and Doi et al. 2005, wild fish may have a greater potential to

14 digest or evacuate inedible material under natural conditions than hatchery-reared fish

15 under artificial conditions. Because the probabilities of hook evacuation were same

16 level in both masu salmon and white-spotted charr in experimental ponds (Doi et al.

17 2005), the evacuation speed of this chapter could be applied on other salmonids in

18 mountain streams.

19   Avoiding deep hooking perfectly is unable regardless of any fishing tackles and

20 methods. Cutting the line is as the last refuge to success in catch and release for

21 deep-hooked fish. Unfortunately, in Japan, most anglers harvest deep-hooked fish,

22 even illegal-sized fish. Therefore, I need to inform anglers about the effectiveness of

23 cutting the line.

24

1   **Table 5.1.** Summary of sample size for each episode.

2

Date	Purpose	Sampling technique	Total number of marked fish captured	Deep-hooked fish [a]	Time from the cut-line release to the first day of recapture (day)
2001/5/22-24	Mark	Electrofishing	415		
2001/6/1	Catch and Release	Angling	95	5	70
2001/6/8	Catch and Release	Angling	72	5	63
2001/6/15	Catch and Release	Angling	66	13	56
2001/6/22	Catch and Release	Angling	61	4	49
2001/6/29	Catch and Release	Angling	69	15	42
2001/7/6	Catch and Release	Angling	84	12	35
2001/7/13	Catch and Release	Angling	69	7	28
2001/7/20	Catch and Release	Angling	81	7	21
2001/7/27	Catch and Release	Angling	72	8	14
2001/8/3	Catch and Release	Angling	66	12	7
2001/8/10-11	Recapture	Angling	103		
2001/8/13-15	Recapture	Electrofishing	263		

3

4   [a] Deep-hooked fish were released by cutting the line.

5

6

7

8   **Table 5.2.** Comparison of the probability of hook evacuation between previous studies

9   and this study.

10

Reference	Species	Fishing method	Time peiod after cutting the line (days)	Probability of hook evacuation (%)		Estimated probability in this study same period afterwards (%)
Schisler and Bergersen (1996)	Rainbow trout	bait fishing	21	25.3	(20 / 79) [a]	16.6
Doi et al. (2005)	White-spotted Charr	bait fishing	81	38.9	(7 / 18)	80.0
Doi et al. (2005)	Masu salmon	bait fishing	81	33.3	(6 / 18)	80.0
Mason and Hunt (1967)	Rainbow trout	bait fishing	120	58.0	(76 / 131)	96.6
Hulbert and Engstrom-Heg 1980)	Brown trout	bait fishing	135	76.7	(23 / 30)	98.3

11

12   [a] Numbers of evacuated hook and deep-hooked fish in parentheses.

13

14

61

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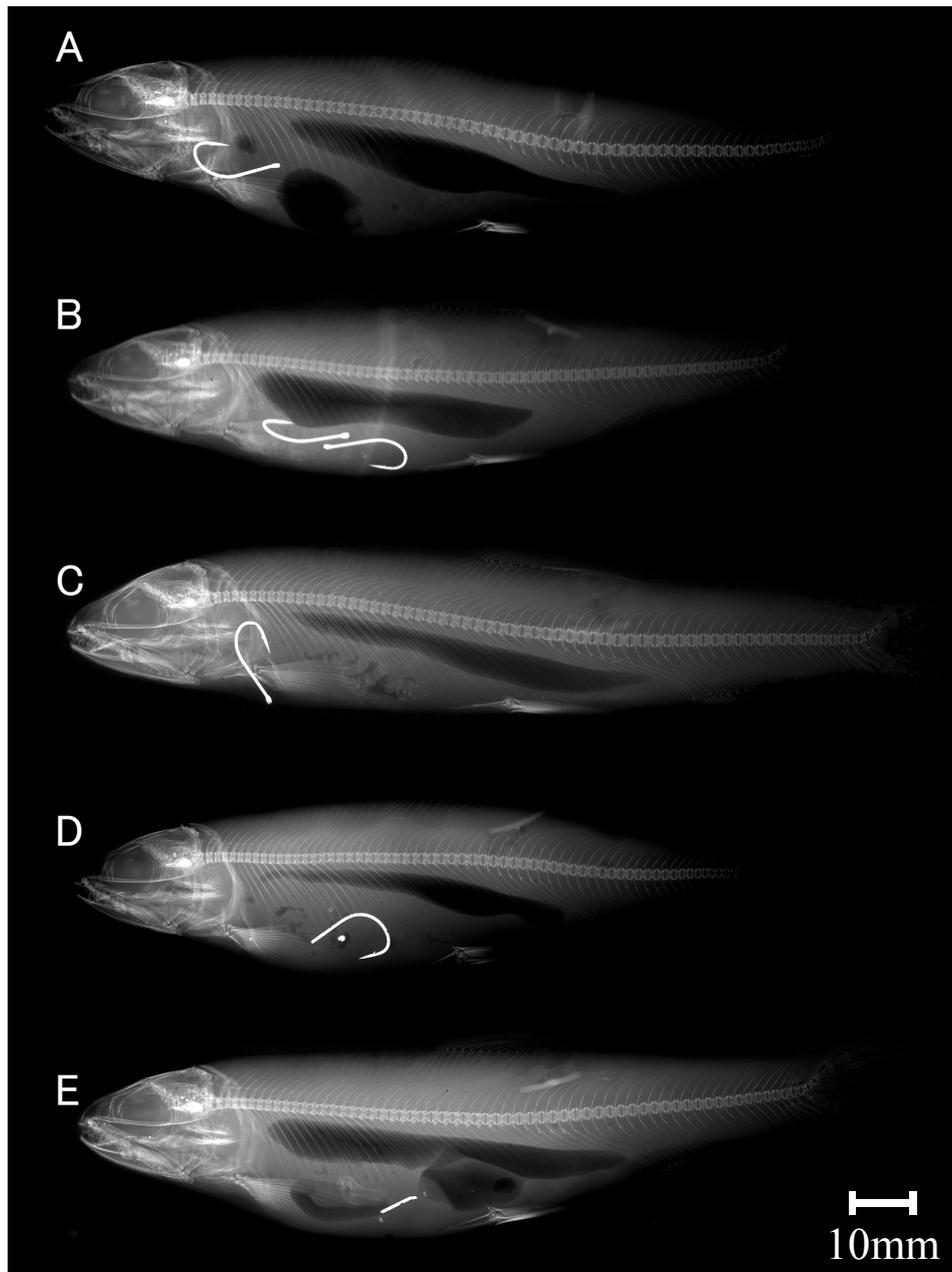
Fig. 5.1. X-ray of deep-hooked fish at various times after cut-line release. A: Seven

days after hooking, the hook is embedded in the esophagus; B: Seven and 14 days

afterwards, one is in the esophagus, and the other lies in the stomach; C: Fifty-six days

afterwards, the hook is embedded in the esophagus and the hook eye protrudes from

the gills; D: Fifty-six days afterwards, the hook lies in the stomach and the hook eye

has dropped off; E: Forty-two days afterwards, part of a hook remains in the stomach.

1
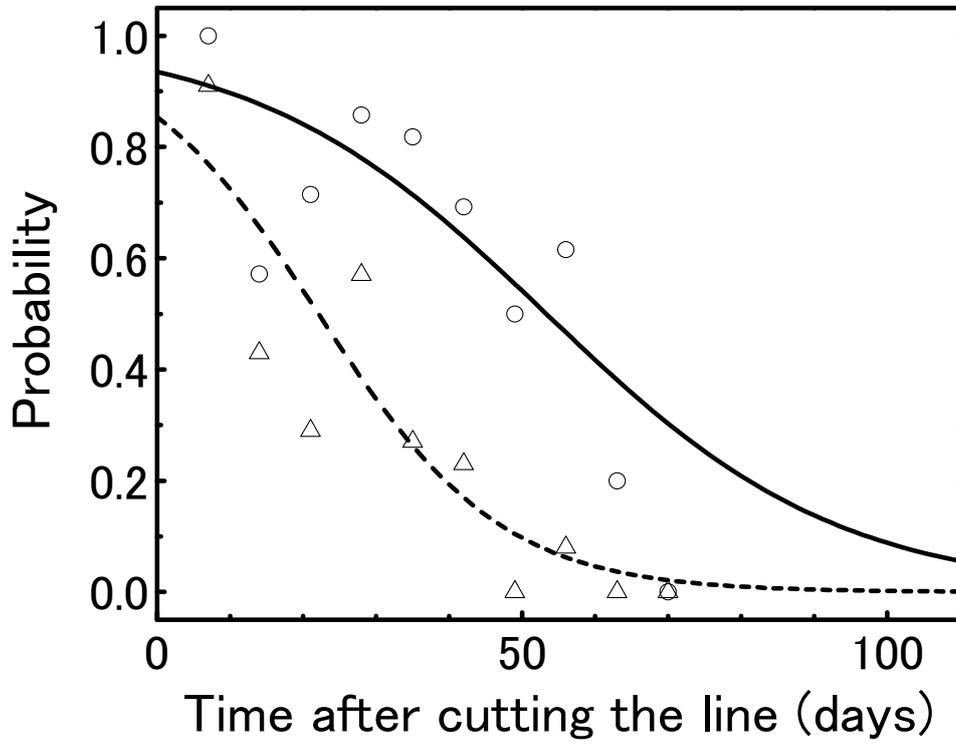
2

3   **Fig. 5.2.** Relationship between time after cutting the line and the probability of the

4   hook remaining (circles and solid line) and being uncorroded (triangles and dashed

5   line) in a white-spotted charr gut. The curves are predicted from the logistic regression

6   model.

7

6

General Discussion

In this dissertation, I have documented the magnitude of the impact of fishing on fish populations and the effectiveness of catch and release fishing for sustaining resources of stream-dwelling salmonids. In the first experiment (Chapter 2), white-spotted charr and red-spotted masu salmon were vulnerable to fishing, although there were differences in the exploitation rates and the relationships between CPUE and abundance with the species. Consequently, in Chapters 3, I investigated the effectiveness of catch and release fishing as a management tool to reduce the impact of fishing on white-spotted charr populations. There was no effect of single catch and release fishing on growth, survival, and vulnerability to fishing. However, some deep-hooked fish died before release, which the hooking mortality was 6.7 %. Therefore, in the subsequent multiple catch and release experiment (Chapter 4 and 5), I cut the line rather than removing the hook to reduce post-release mortality for deep-hooked fish. As a result, only one fish (0.14%) died before release. In Chapter 4, vulnerability to fishing was related to fork length, sex, and the number of experience of being caught, as an index of individuality. Therefore, caught fish would be valuable to anglers because these fish would be caught repeatedly if catch and release program were successful. In Chapter 5, I followed the fate of deep-hooked white-spotted charr released by cutting the fishing line. The results suggest that the survival rates of fish released by cutting the line are sufficiently high to be encouraging in a natural environment. Furthermore, the hooks remaining in the gut corroded and evacuated

1   with time.

2   *Recreational fishing in mountain streams*

3   I summarized typical features of recreational fishing in mountain streams. I

4   proposed two features of recreational fishing; 1. recreational fishermen, unlike purse

5   seine fishermen, capture individual fish, 2. their capture success depends on foraging

6   behavior of fish. Therefore, the capture event can affect other free individuals during a

7   fishing bout. Figure 6.1 presents the relationship between fishing effort (time) and

8   effective abundance (the number of catchable individuals) in a mountain stream pool.

9   Effective abundance is initially equal to actual abundance. Thereafter, capture events

10   decrease the effective abundance both by the capture event itself and by startling other

11   individuals that are not vulnerable during a fishing bout. In fact, I observed that some

12   fish went into hiding when another fish was captured.

13   The number of fish captured can be defined as the product of effective abundance

14   and catchability (q) at a time t (Fig. 6.2). The number of startled fish increases at a

15   certain rate (R; not always constant). Values of "q" should vary between species.

16   Individuality and body size could be inherence factors to fluctuate "q" at individual

17   level as in Chapter 4. Values of "R" should also vary between species. For example, in

18   white-spotted charr, the value of R would be negligible, whereas in red-spotted masu

19   salmon, it would be substantial (Chapter 2). In this manner, fishing success (i.e.,

20   number captured) should be alterative by capture events themselves, because

21   abundances and fishing grounds in mountain streams are much smaller than lake and

22   ocean.

23   *Vulnerable to fishing for stream-dwelling salmonids*

24   In Chapter 2, the exploitation rates (total number of fish caught / total abundance)

1   of white-spotted charr and red-spotted masu salmon were 17.9 % (46 / 257) and

2   10.8 % (90 / 830), respectively, even though the field study was conducted in popular

3   fishing area. In Chapter 3, white-spotted charr were caught by fishing approximately

4   the same numbers as those caught by electrofishing. In Chapter 4, 74 fish were caught

5   on average in each fishing episode, which corresponds to 17.7% of all marked fish.

6   These results indicate that stream-dwelling salmonids, especially white-spotted charr,

7   were seriously vulnerable to recreational fishing. Dunham et al. (2002) pointed out

8   that small cutthroat trout populations may actually be extirpated by fishing. Therefore,

9   the substantial intervention is necessary to sustain and conserve the recreational

10   fishing resources (Post et al. 2002).

11   *Selectivity due to phenotypic variation and individuality*

12   Generally, recreational fishermen purse the trophy-sized fish (i.e., large fish).

13   However, random fishing experiments also caught larger fish selectively in Chapter 2,

14   3, 4. Vulnerability to fishing was related to fork length and growth rate in Chapter 3

15   and to fork length, sex, and the number of experience of being caught, as an index of

16   individuality, in Chapter 4. Specifically, the effect of fork length was very strong in

17   both Chapter 3 and 4. Catch and release fishing is effective from the aspect of

18   conserving larger fish, which are valuable to anglers as trophy fish, and larger fish are

19   caught repeatedly, in contrast to smaller individuals. Gruson (1998) proposed that

20   larger fish should be caught and released to sustain resources. A simulation suggested

21   that the conservation of larger fish rather than small fish was the most effective

22   harvesting method for sustaining a fish population (Yokota et al. 2003). Indeed,

23   significant reductions in the median length and weight of lake trout (*S. namaycush*)

24   were observed after lifting the ban on fishing in an Arctic lake, where fishing had been

1 illegal for a long time (McDonald and Hershey 1989).

2 *Why larger fish were more vulnerable*

3   Many studies have documented that larger fish are more vulnerable to fishing

4 than smaller fish (e.g., Wilde et al. 2003; Askey et al. 2006; Tsuboi and Endou 2008,

5 see also Chapter 2). I propose four reasons for the higher vulnerable to fishing of

6 larger fish in my studies: 1. Physical limits of hook size; 2. Selectivity for prey size; 3.

7 Hierarchy of dominance; and 4. Size of territory.

8   Clearly, there is a physical limit to the size of the hook that a fish can take into its

9 mouths. For 100-mm salmonid fish, the live bait used in my experiments (straight

10 body length $= 22.8 \pm 1.7$ mm) corresponds to the maximum prey size (Keeley and

11 Grant 2001). In addition, larger dominant fish feed selectively on larger prey,

12 compared with the prey size of their subordinates (Nakano 1995b). In stream-dwelling

13 salmonids, the average prey size is approximately 6 mm for 200-mm fish (Keeley and

14 Grant 2001); therefore, larger fish tend to eat live bait over 20 mm in body length.

15 Dominance hierarchies must also play an important role in the positive association

16 between fish size and fishing vulnerability. In stream-dwelling salmonids, the relative

17 competitive ability of individuals within a local group is usually determined by body

18 size (e.g., Fausch 1984; Elliott 1990; Nakano 1995b). In addition, as larger fish have

19 larger territories (Elliott 1990; Grant and Kramer 1990), they should have more

20 opportunities to feed on bait (Lewynsky and Bjornn 1987).

21 *Effectiveness of catch and release fishing for sustaining resources*

22   Because the exploitation rates (total number of fish caught / total abundance)

23 were very high in white-spotted charr and red-spotted masu salmon (Chapter 2), catch

24 and release fishing can contribute to sustain abundance and relax the impact of

1 selective exploitation by fishing, if high survival rates were expected in released

2 individuals. The results presented in Chapter 3 showed no evidence that catch and

3 release fishing affects growth, survival, and vulnerability to fishing. Chapter 4

4 reported that three fish were caught seven times during 11 fishing episodes. Based on

5 my studies and the reference about the hooking mortality in artificial ponds for

6 white-spotted charr and masu salmon (Doi et al. 2004), I conclude that catch and

7 release fishing is effective for sustaining stream-dwelling salmonids populations.

8 Schill et al. (1986) estimated that cutthroat trout in the Yellowstone River were caught

9 and released an average of 9.7 times over 45 days. Carline et al. (1991) argued that

10 catch and release regulations enable recycling of salmonids.

11 *Comparison of hooking mortalities between present and previous studies*

12   I used natural baits in all fishing experiments, which hooking mortality is higher

13 than that from artificial baits (e.g., lure and fly) (reviewed in Taylor and White 1992;

14 Muoneke and Childress 1994; Bartholomew and Bohnsack 2005). Consequently, 6.7%

15 of hooking mortality in white-spotted charr (Chapter 3) was substantially lower than

16 31.4% of non-anadromous trout by natural bait fishing (reviewed in Taylor and White

17 1992). As was expected, hooking mortality in previous studies might be overestimated

18 in lentic water (i.e., artificial ponds), where the incidence of deep hooking increases

19 because it should be hard to detect the bite of fish.

20   Doi et al. (2004) reported that there were no differences in hooking mortality

21 between white-spotted charr and masu salmon in experimental ponds, using

22 natural-bait fishing. Therefore, my results could be applied on other salmonids in

23 mountain streams. Additionally, Bartholomew and Bohnsack (2005) analyzed 276

24 reports of hooking mortality and pointed out that mortality distributions were similar

1 for salmonids, marine, and freshwater species. My result could be one of the standards

2 of hooking mortality in natural habitats.

3 *Minimization of hooking mortality before release*

4 The studies in Chapter 4 and Chapter 5 demonstrated that cutting the line is an

5 effective release method for deep-hooked fish. Hooking mortality before release was

6 negligible (0.14%; 1 / 735 fish) in Chapter 4 and was significantly lower than the rate

7 for the experiments in Chapter 3 (6.7%; 19 / 282), which involved the same equipment

8 but omitted line cutting (*G*-test, $p < 0.001$). In Chapter 5, the hooks remaining after

9 line cutting tended to be corroded or evacuated. This result would be applicable to

10 other situations, although the effectiveness of line cutting depends on fishing

11 conditions, e.g., marine environments, where corrosion rates will differ. Similar

12 studies are required on other species and in other environments, as well as with other

13 hook materials. For sustainable recreational fisheries, the innovation and

14 dissemination of new types of fishing gear will benefit conservation.

15 *Resource management for sustainable recreational fisheries*

16 The results in this dissertation indicate that catch and release regulations can be

17 an effective management tool for sustaining recreational fisheries, because anglers can

18 continuously catch fish while conserving the fish populations. However, reducing

19 hooking mortality is critical in order for conservation-based catch and release

20 guidelines to ensure the sustainability of recreational fisheries (Cooke and Suski 2005).

21 If cutting the line were to become popular or were to be adopted as a regulation,

22 hooking mortality should decrease dramatically.

23

24

1

2 Fishing effort (t)
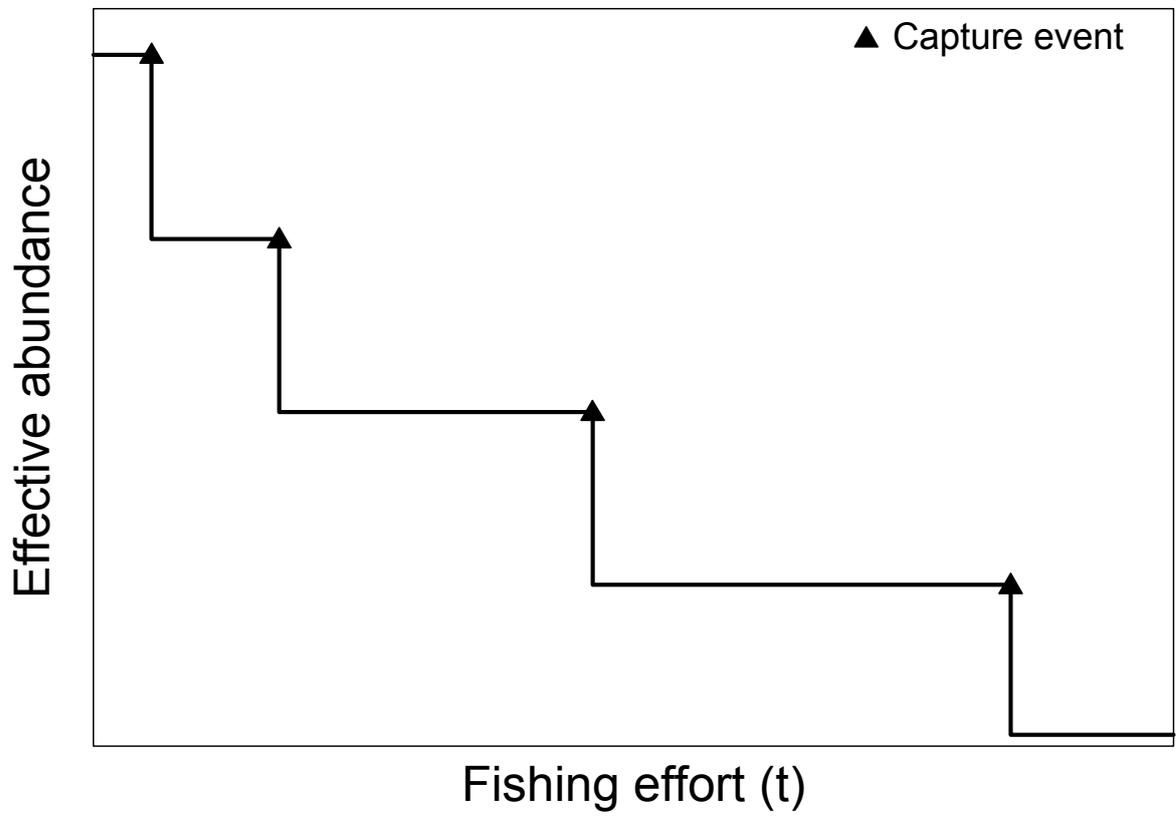
3

4 **Fig. 6.1.** Schema depicting the intergradation of the effective abundance during a

5 fishing experiment in a mountain stream pool.

6

1
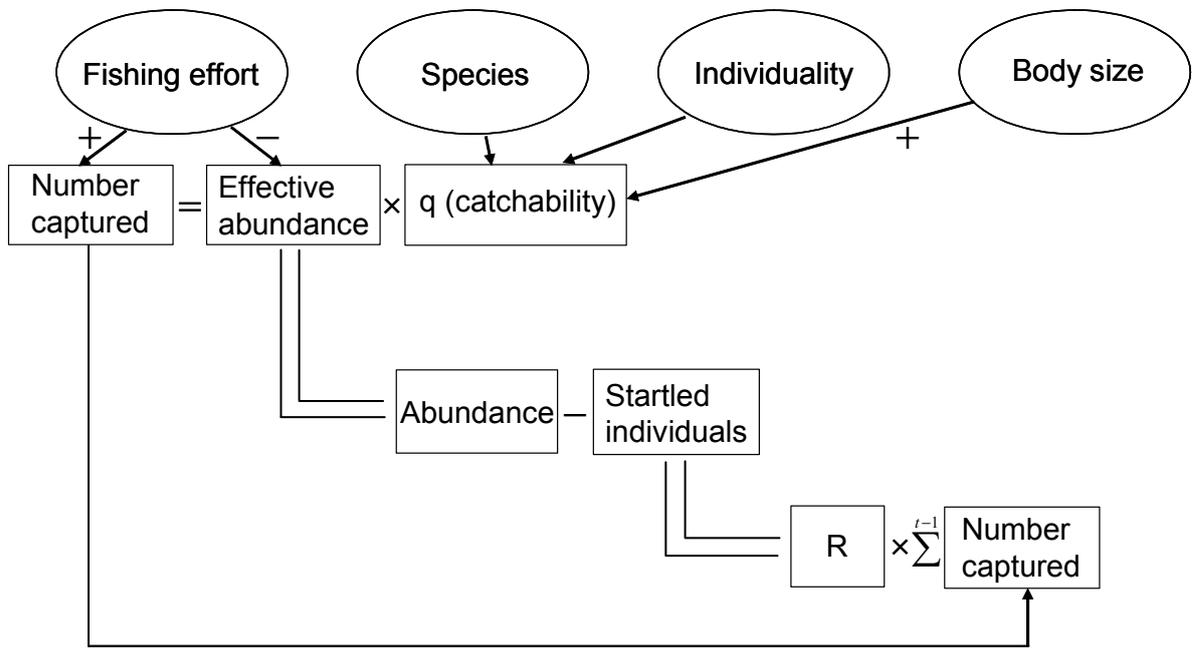
2

3

4 **Fig. 6.2.** Relationship between fishing and fish abundance with biological factors at

5 time t, incorporating results from Chapters 2, 3, and 4. Solid arrows indicate positive

6 (+), negative (−), or specific effects, which were detected during this dissertation

7 research. R is a certain rate and not always constant.

8

7

References

Agresti, A. 2002. Categorical data analysis, 2nd edition. Wiley, New York.

Alverson, D. L., Freeberg, M. H., Pope, J. G., and Murawski, S. A. 1994. A global assessment of fisheries bycatch and discards. FAO Fish. Tech. Pap. No. 339. Rome. pp. 233.

Arlinghaus, R., Mehner, T., and Cowx, I. G. 2002. Reconciling traditional inland fisheries management and sustainability in industrialized countries, with emphasis on Europe. Fish and Fisheries **3**: 261–316.

Askey, P. J., Richards, S. A., Post, J. R., and Parkinson, E. A. 2006. Linking angling catch rates and fish learning under catch-and-release regulations. N. Am. J. Fish. Manage. **26**: 1020–1029.

Bannerot, S. P., and Austin, C. B. 1983. Using frequency distributions of catch per unit effort to measure fish-stock abundance. Trans. Am. Fish. Soc. **112**: 608–617.

Bartholomew, A., and Bohnsack, J. A. 2005. A review of catch-and-release angling mortality with implications for no-take reserves. Rev. Fish. Sci. **15**: 129–154.

Bettoli, P. W., and Osborne, R. S. 1998. Hooking mortality and behavior of striped bass following catch and release angling. N. Am. J. Fish. Manage. **18**: 609–615.

Beukema, J. J. 1970. Angling experiments with carp *Crprinus carpio*. II. Decreasing catchability through one-trial learning. Net. J. Zool. **20**: 81–92.

Booth, R. K., Kieffer, J. D., Davidson, K., Bielak, A. T., and Tufts, B. L. 1995. Effects of late-season catch and release angling on anaerobic metabolism, acid-base status, survival, and gamete viability in wild Atlantic salmon *Salmo salar*. Can. J. Fish. Aquat. Sci. **52**: 283–290.

Burnham, K. P., and Anderson, D. R. 2002. Model selection and multimodel inference, 2nd edition. Springer, New York.

Carline, R. F., Beard, T., and Hollender, B. A. 1991. Response of wild brown trout to elimination of stocking and no-harvest regulations. N. Am. J. Fish. Manage. **11**: 253–266.

Clark, C. W. 1985. Bioeconomic modelling and fisheries management. Wiley, New York.

Coleman, F. C., Figueira, W. F., Ueland, J. S., and Crowder L. B. 2004. The impact of United States recreational fisheries on marine fish populations. Science **305**:

1958–1960.

Cooke, S. J., and Cowx, I. G. 2004. The role of recreational fishing in global fish crises.
    BioScience **54**: 857–859.

Cooke, S. J., and Schramm, H. L. 2007. Catch-and-release science and its application to
    conservation and management of recreational fisheries. Fish. Manage. Ecol. **14**:
    73–79.

Cooke, S. J., and Suski, C. D. 2004. Are circle hooks an effective tool for conserving
    marine and freshwater recreational catch-and-release fisheries? Aqua. Conserv. Mar.
    Freshw. Ecosyst. **14**: 229–326.

Cooke, S. J., and Suski, C. D. 2005. Do we need species-specific guidelines for
    catch-and-release recreational angling to effectively conserve diverse fishery
    resources? Biodivers. Conserv. **14**: 1195–1209.

Cooke, S. J., and Wilde, G. R. 2007. The fate of fish released by recreational anglers. *In*
    By-catch reduction in the world's fisheries. *Edited by* S. J. Kennelly. Springer,
    Dordrecht. pp. 181–224.

Cox, S. P., and Walters, C. 2002. Modeling exploitation in recreational fisheries and
    implications for effort management on British Columbia rainbow trout lakes. N. Am.
    J. Fish. Manage. **22**: 21–34.

Doi, T., Nakamura, T., Yokota, M., Maruyama, T., Watanabe, S., Noguchi, H., Sano, Y.,
    and Fujita, T. 2004. Hooking mortality and growth of caught and released Japanese
    charr *Salvelinus leucomaenis* and masu salmon *Oncorhynchus masou masou* in
    experiment ponds. Nippon Suisan Gakkaishi **70**: 706–713.

Doi, T., Nakamura, T., Yokota, M., Maruyama, T., Watanabe, S., Noguchi, H., Sano, Y.,
    and Fujita, T. 2005. Destiny of hooks remaining in the body of Japanese charr
    Salvelinus leucomaenis and masu salmon *Oncorhynchus masou masou*. Nippon
    Suisan Gakkaishi **71**: 348–353.

Dunham. J. B., Adams, S. B., Schroeter, R. E., and Novinger, D. C. 2002. Alien
    invasions in aquatic ecosystems: Toward an understanding of brook trout invasions
    and potential impacts on inland cutthroat trout in western North America. Rev. Fish
    Biol. Fish. **12**: 373–391.

Elliott, J. M. 1990. Mechanisms responsible for population regulation in young
    migratory trout, *Salmo Trutta*. III. The role of territorial behaviour. J. Anim. Ecol.
    59: 803–818.

Endou, S., Tsuboi, J., and Iwata, T. 2006. Effects of damming on the persistence of
    white-spotted charr and red-spotted masu salmon populations. Japan. J. Conserv.
    Ecol. **11**: 4–12.

Fausch, K. D. 1984. Profitable stream positions for salmonids: relating specific growth rate to net energy gain. Can. J. Zool. **62**: 441–451.

Fernö, A., and Huse, I. 1983. The effect of experience on the behaviour of cod (*Gadus morhua* L.) towards a baited hook. Fish. Res. **2**: 19–28.

Gaertner, D., and Dreyfus-Leon, M. 2004. Analysis of non-linear relationships between catch per unit effort and abundance in a tuna purse-seine fishery simulated with artificial neural networks. ICES J. Mar. Sci. **61**: 812–820.

Grant, J. W. A., and Kramer, D. L. 1990. Territory size as a predictor of the upper limit to population density of juvenile salmonids in streams. Can. J. Fish. Aquat. Sci. **47**: 1724–1737.

Greenberg, L. A., and Giller, P. S. 2001. Individual variation in habitat use and growth of male and female brown trout. Ecography **24**: 212–224.

Griffith, J. S. 1999. Coldwater streams. *In* Inland fisheries management in North America 2nd ed. *Edited by* C. C. Kohler and W. A. Hubert. American Fisheries Society, Maryland, US. pp. 481–504.

Grimm, D. 2004. Sportfishers on the hook for dwindling U.S. fish stocks. Science **305**: 1235.

Gruson, L. Throwing back undersize fish is said to encourage smaller fly. *In* The science Times book of fish. *Edited by* N. Wade. The New York Times, New York. pp. 152–156.

Gustaveson, A. W., Wydoski, R. S., and Wedemeyer, G. A. 1991. Physiological response of large mouth bass to angling stress. Trans. Am. Fish. Soc. **120**: 629–636.

Hackney, P. A., and Linkous, T. E. 1978. Striking behavior of the largemouth bass and use of the binominal distribution for its analysis. Trans. Am. Fish. Soc. **107**: 682–688.

Hardy, I. C. W. 2002. Sex ratios: concepts and research methods. Cambridge University Press, Cambridge.

Harley, S. J., Myers, R. A., and Dunn, A. 2001. Is catch-per-unit-effort proportional to abundance? Can. J. Fish. Aquat. Sci. **58**: 1760–1772.

Hilborn, R., and Walters, C. J. 1992. Quantitative fisheries stock assessment: choice, dynamics, and uncertainty. Chapman and Hall, New York.

Holtby, L. B., Kadowaki, R. K., and Simpson, K. S. 1992. Factors affecting the vulnerability of juvenile Coho (*Oncorhynchus kisutch*) and Chinook salmon (*O. tshawytscha*) in a saltwater sport fishery. Can. J. Fish. Aquat. Sci. **49**: 2164–2178.

Homans, G. C. 1974. Social behavior: Its elementary forms, 2nd ed. Harcourt Brace Jovanovich, New York.

Hulbert, P. J., and Engstrom-Heg, R. 1980. Hooking mortality of worm-caught hatchery brown trout. NY Fish Game J. **27**: 1–10.

Huntingford, F. A. 1976. The relationship between anti-predator behavior and aggression among conspecifics in the three-spined stickleback, *Gasterosteus aculeatus*. Anim. Behav. **24**: 245–260.

Iguchi, K., Matsubara, N., and Hakoyama, H. 2001. Behavioural individuality assessed from two strains of cloned fish. Anim. Behav. **61**: 351–356.

Ishigaki, K. 1984. Exploring the mystery of charrs. Iwanami-shoten, Tokyo. (In Japanese.)

Jenkins, T. M. 2003. Evaluating recent innovations in bait fishing tackle and technique for catch and release of rainbow trout. N. Am. J. Fish. Manage. **23**: 1098–1107.

Jennings, S., Kaiser, M. J., and Reynolds, J. D. 2001. Fishing effects on populations and communities. *In* Marine Fisheries Ecology. Blackwell Science, Oxford. pp. 239–257.

Johnson, B. M., and Carpenter, S. R. 1994. Functional and numerical responses: a framework for fish-angler interactions? Ecol. Appl. **4**: 808–821.

Johnsson, J. I., Åkerman, A. 1998. Intersexual differences in aggression in juvenile rainbow trout. J. Fish Biol. **52**: 1292–1294.

Johnsson, J. I., Sernland, E., Blixt, M. 2001. Sex-specific aggression and antipredator behaviour in young brown trout. Ethology **107**: 587–599.

Keeley, E. R., and Grant, J. W. A. 2001. Prey size of salmonid fishes in streams, lakes, and oceans. Can. J. Fish. Aquat. Sci. **58**: 1122–1132.

Kieffer, J. D., Kubacki, M. R., Phelan, F. J. S., Philipp, D. P., and Tufts, B. L. 1995. Effects of catch-and-release angling on nesting male smallmouth bass. Trans. Am. Fish. Soc. **124**: 70–76.

Lewin, W. C., Arlinghaus, R., and Mehner, T. 2006. Documented and potential biological impacts of recreational fishing: Insights for management and conservation. Rev. Fish. Sci. **14**: 305–367.

Lewynsky, V. A., and Bjornn, T. C. 1987. Response of cutthroat and rainbow trout to experimental catch-and-release fishing. *In* Catch-and-release fishing: a decade of experience. *Edited by* R. A. Barnhart and T. D. Roelofs. California Cooperative Fishery Research Unit, Arcata. pp. 16–23.

Mason, J. W., and Hunt, R. L. 1967. Mortality rates of deeply hooked rainbow trout. Prog. Fish-Cult. **29**: 87–91.

Matsuishi, T., Narita, A., and Ueda, H. 2002. Population assessment of sockeye salmon *Oncorhynchus nerka* caught by recreational angling and commercial fishery in Lake

Toya, Japan. Fish. Sci. **68**: 1205–1211.

Matsuishi, T., Wada, T., Matsumiya, Y., and Kishino, H. 1993. Optimal school selection and abundance index in purse seine fishery. Nippon Suisan Gakkaishi **59**: 273–278.

McDonald, M. E., and Hershey, A. E. 1989. Size structure of a lake trout (*Salvelinus namaycush*) population in an arctic lake: influence of angling and implications for fish community structure. Can. J. Fish. Aquat. Sci. **46**: 2153–2156.

Metcalf, J. C., Rose, K. E., and Rees, M. 2003. Evolutionary demography of monocarpic perennials. Trends Ecol. Evol. **18**: 471–480.

Mezzera, M., and Largiadèr, C. R. 2001. Evidence for selective angling of introduced trout and their hybrids in a stocked brown trout population. J. Fish Biol. **59**: 287–301.

Morita, K., and Morita, S. H. 2002. Rule of age and size at maturity: individual variation in the maturation history of resident white-spotted charr. J. Fish Biol. **61**: 1230–1238.

Morita, K., Yamamoto, S., Hoshino, N. 2000. Extreme life history change of white-spotted char *Salvelinus leucomaenis* after damming. Can. J. Fish. Aquat. Sci. **57**: 1300–1306.

Mullner, S. A., Hubert, W. A., and Wesche, T. A. 1998. Snorkeling as an alternative to depletion electrofishing for estimating abundance and length-class frequencies of trout in small streams. N. Am. J. Fish. Manage. **18**: 947–953.

Muoneke, M. I., and Childress, W. M. 1994. Hooking mortality: a review for recreational fisheries. Rev. Fish. Sci. **2**: 123–156.

Nakamura, T., Maruyama, T., and Watanabe, S. 2002. Residency and movement of stream-dwelling Japanese charr, *Salvelinus leucomaenis*, in a central Japanese mountain stream. Ecol. Freshw. Fish **11**: 150–157.

Nakano, S. 1995a. Competitive interactions for foraging microhabitats in a size-structured interspecific dominance hierarchy of two sympatric stream salmonids in a natural habitat. Can. J. Zool. **73**: 1845–1854.

Nakano, S. 1995b. Individual differences in resource use, growth and emigration under the influence of a dominance hierarchy in fluvial red-spotted masu salmon in a natural habitat. J. Anim. Ecol. **64**: 75–84.

Nakano, S., Kachi, T., and Nagoshi, M. 1990. Restricted movement of the fluvial form of red-spotted masu salmon, *Oncorhynchus masou rhodurus*, in a mountain stream, central Japan. Japan. J. Ichthyol. **37**: 158–163.

Nelson, K. L. 1998. Catch-and-release mortality of striped bass in the Roanoke River, North Carolina. N. Am. J. Fish. Manage. **18**: 25–30.

Newby, J. R., Hansen, M. J., Newman, S. P., and Edwards, C. J. 2000. Catchability of walleyes to angling in Escanaba Lake, Wisconsin, 1980–1995. N. Am. J. Fish. Manage. **20**: 873–881.

Noble, R. L. and Jones, T. W. 1999. Managing fisheries with regulations. *In* Inland fisheries management in North America 2nd ed. *Edited by* C. C. Kohler and W. A. Hubert. American Fisheries Society, Maryland, US. pp. 455–477.

O'Grady, K. T., and Hughes, P. C. R. 1980. Factorial analysis of an experimental comparison of three methods of fishing for rainbow trout, *Salmo gairdneri* Richardson, in still water. J. Fish Biol. **16**: 257–264.

Pankhurst, N. W., and Dedual, M. 1994. Effects of capture and recovery on plasma levels of cortisol, lactate and gonadal steroids in a natural population of rainbow trout. J. Fish Biol. **45**: 1013–1025.

Paul, A. J., Post, J. R., and Stelfox, J. D. 2003. Can anglers influence the abundance of native and nonnative salmonids in a stream from the Canadian Rocky Mountains? N. Am. J. Fish. Manage. **23**: 109–119.

Peterman, R. M., and Steer, G. J. 1981. Relation between sport-fishing catchability coefficients and salmon abundance. Trans. Am. Fish. Soc. **110**: 585–593.

Pope, K. L., and Wilde, G. R. 2004. Effect of catch-and-release angling on growth of largemouth bass, *Micropterus salmoides*. Fish. Manage. Ecol. **11**: 39–44.

Policansky, D. 2002. Catch-and-release recreational fishing: a historical perspective. *In* Recreational fisheries: ecological, economic, and social evaluation. *Edited by* T. J. Pitcher and C. Hollingworth. Blackwell Science, Oxford, UK. pp. 74–94.

Post, J. R., Sullivan, M., Cox, S., Lester, N. P., Walters, C. J., Parkinson, E. A., Paul, A. J., Jackson, L., and Shuter, B. J. 2002. Canada's recreational fisheries: the invisible collapse? Fisheries **27(1)**: 6–17.

Raat, A. J. P. 1985. Analysis of angling vulnerability of common carp, *Cyprinus carpio* L., in catch-and-release angling in ponds. Aquacul. Fish. Manage. **16**: 171–187.

Reyes-Gavilán, F. G., Ojanguren, A. F., and Braña, F. 1997. The ontogenetic development of body segments and sexual dimorphism in brown trout (*Salmo trutta* L.). Can. J. Zool. **75**: 651–655.

Richards, L. J., and Schnute, J. T. 1986. An experimental and statistical approach to the question: is CPUE an index of abundance? Can. J. Fish. Aquat. Sci. **43**: 1214–1227.

Rodgers, J. D., Solazzi, M. F., Johnson, S. L., and Buckman, M. A. 1992. Comparison of three techniques to estimate juvenile coho salmon populations in small streams. N. Am. J. Fish. Manage. **12**: 79–86.

1   Sakata, K., Kondou, T., Takeshita, N., Nakazono, A., and Kimura, S. 2005. Movement
2   of the fluvial form of masu salmon, *Oncorhynchus masou masou,* in a mountain
3   stream in Kyushu, Japan. Fish. Sci. **71**: 333–341.
4   Sato, T., and Watanabe, K. 2004. Spawning site characteristics of Kirikuchi charr
5   *Salvelinus leucomaenis japonicus*: southernmost population, and effects of angling
6   pressure. Japan. J. Ichtyol. **51**: 51–59.
7   Schill, D. J. 1996. Hooking mortality of bait-caught rainbow trout in an Idaho trout
8   stream and a hatchery: implications for special-regulation management. N. Am. J.
9   Fish. Manage. **16**: 348–356.
10   Schill, D. J., Griffith, J. S., and Gresswell, R. E. 1986. Hooking mortality of cutthroat
11   trout in a catch-and-release segment of the Yellowstone River, Yellowstone National
12   Park. N. Am. J. Fish. Manage. **6**: 226–232.
13   Schisler, G. J., and Bergersen, E. P. 1996. Postrelease hooking mortality of rainbow trout
14   caught on scented artificial baits. N. Am. J. Fish. Manage. **16**: 570–578.
15   Siepker, M. J. , Ostrand, K. G. O., and Wahl, D. H. 2006. Effects of angling on feeding
16   by largemouth bass. J. Fish Biol. **69**: 783–793.
17   Sneddon, L. U., Braithwaite, V. A., and Gentle, M. J. 2003. Do fishes have nociceptors?
18   Evidence for the evolution of a vertebrate sensory system. Proc. R. Soc. Lond. B.
19   **270**: 1115–1121.
20   Sokal, R. R., Rohlf, F. J. 1995. Biometry, third edition. W. H. Freeman and Company,
21   New York.
22   Takami, T., Kitano, F., and Nakano, S. 1997. High water temperature influences on
23   foraging responses and thermal deaths of Dolly Varden *Salvelinus malma* and
24   white-spotted charr *S. leucomaenis* in a laboratory. Fish. Sci. **63**: 6–8.
25   Takami, T., and Sato, H. 1998. Influence of high water temperature on feeding
26   responses and thermal death of juvenile masu salmon under aquarium settings.
27   Scientific Reports of the Hokkaido Fish Hatchery **52**: 79–82.
28   Tanaka, A. 2003. The hooking mortality of land-locked salmonids after C&R, ―review
29   cases in USA―. Newsletter of Naisuimen **32**: 45–49. (In Japanese.)
30   Taylor, M. J. and White, K. R. 1992. A meta-analysis of hooking mortality of
31   nonanadromous trout. N. Am. J. Fish. Manage. **12**: 760–767.
32   Thurow, R. F. 1994. Underwater methods for study of salmonids in the Intermountain
33   West. General Technical Report INT-GTR-307. Department of Agriculture, Forest
34   Service, Intermountain Research Station, Ogden.
35   Thurow, R. F., and Schill, D. J. 1996. Comparison of day snorkeling, night snorkeling,
36   and electrofishing to estimate bull trout abundance and size structure in a

second-order Idaho stream. N. Am. J. Fish. Manage. **16**: 314–323.

Tsuboi, J., Morita, K., and Matsuishi, T. 2002. Effects of catch-and-release angling on growth, survival and catchability of white-spotted charr *Salvelinus leucomaenis* in wild streams. Nippon Suisan Gakkaishi **68**: 180–185.

Tsuboi, J., and Morita, K. 2004. Selectivity effects on wild white-spotted charr (*Salvelinus leucomaenis*) during a catch and release fishery. Fish. Res. **69**: 229–238.

Tsuboi, J., Morita, K., and Ikeda, H. 2006. Fate of deep-hooked white-spotted charr after cutting the line in a catch-and-release fishery. Fish. Res. **79**: 226–230.

Tsuboi, J., and Endou, S. 2008. Relationships between catch per unit effort, catchability, and abundance based on actual measurements of salmonids in a mountain stream. Trans. Am. Fish. Soc. **137**: 496–502.

White, G. C., Burnham, K. P., Otis, D. L., and Anderson, D. R. 1978. User's manual for program CAPTURE. Utah State University Press, Logan.

Wilde, G. R., Pope, K. L., and Durham, B. W. 2003. Lure-size restrictions in recreational fisheries. Fisheries **28(6)**, 18–24.

Wydoski, R. S. 1977. Relation of hooking mortality and sublethal hooking stress to quality fishery management. *In* Catch-and-Release Fishing as a Management Tool. *Edited by* R. A. Barnhart and T. D. Roelofs. Humboldt State University, California. pp. 43–87.

Yamamoto, S., Kohara, M., Kohno, N., Kawanobe, M., and Moteki, M. 2001. Changes of CPUE and population size on wild white spotted charr, *Salvelinus leucomaenis* under catch-and-release regulations using fly-fishing. Suisanzoshoku. **49**: 425–429.

Yamamoto, S., Nakano, S., and Tokuda, Y. 1992. Variation and divergence of the life-history of Japanese charr *Salvelinus leucomaenis* in an artificial lake-inlet stream system. Jpn. J. Ecol. **42**: 149–157.

Yamamoto, T., Ueda, H., and Higashi, S. 1998. Correlation among dominance status, metabolic rate and otolith size in masu salmon. J. Fish Biol. **52**: 281–290.

Yokota, M., Nakamura, T., Watanabe, S., and Takahashi, S. 2003. Effectiveness of fishing management on the Japanese Charr *Salvelinus leucomaenis* population. Suisanzoushoku **51**: 25–29.

Yokoyama, S. 1998. Morphometric analysis and tagging experiments for stock discrimination of cresthead flounder *Pleuronectes schrenki* around Hokkaido. Fish. Sci. **64**: 373–378.

Yoneyama, K., Yagi, S., and Kawamura, G. 1992. Catchability of individual tilapia *Tilapia mossambica* in Tank. Nippon Suisan Gakkaishi **58**: 1867–1872.

Yoneyama, K., Matsuoka, T., and Kawamura, G. 1996. The effect of starvation on

1   individual catchability and hook-avoidance learning of rainbow trout. Nippon

2   Suisan Gakkaishi **62**: 236–242.

3   Zippen, C. 1958. The removal method of population estimation. J. Wildlife Manage. **22**:

4   82–90.