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1 Recreational fisheries as a conservation tool for endemic Dolly Varden *Salvelinus*

2 *malma miyabei* in Lake Shikaribetsu, Japan

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21

22 Abstract

23 Recreational angling is a globally popular leisure, which can be a threat or a useful
24 conservation tool depending on the management strategy. Miyabe charr *Salvelinus*
25 *malma miyabei* is an endemic fish that inhabits Lake Shikaribetsu, and a management
26 program was established to harmonize recreational fisheries and conservation. To
27 examine the suitability of this program, a population assessment was conducted with
28 cooperation of anglers. The population size in 2014 assessed by tag-and-release angling
29 was estimated to be 105,300 (95% CI: 37,300–178,600), much higher than reported
30 estimate in 1995. Further, angling mortality was estimated to be quite low. Moreover, no
31 decreasing population trend was detected on analysing 8 years of angler’s catch data.
32 Consequently, angling has facilitated stock assessments of Miyabe charr under the
33 current program. This case is a good example of recreational angling acting as a
34 conservation tool under appropriate management.

35

36 Key words: angling, catch-and-release, conservation, Dolly Varden, Miyabe charr,
37 recreational fisheries

38

39 **Introduction**

40 Recreational fisheries are an important use of fish resources in most parts of the
41 world [1,2], particularly in inland waters of industrialized countries [3]. Because the
42 catch of recreational anglers is not sometimes self-regulated, recreational fisheries may
43 lead to the collapse of fish populations in the same manner as commercial fisheries [4].
44 Therefore, recreational fisheries management is essential for the sustainable use of
45 inland fish stocks.

46 Various management tools and strategies, including bag limits, fishing gear
47 restrictions and a limit on the number of daily anglers, have been introduced to facilitate
48 sustainable recreational fisheries [5,6]. In addition to these fishing restrictions,
49 catch-and-release can be an effective tool for maintaining fish populations if the
50 after-release mortality is low, because anglers can receive pleasure from the activity in
51 some kind of angling [5-7]. There are some instances where the establishment of
52 appropriate fishing regulations, including catch-and-release, has resulted in sustainable
53 recreational fisheries [8].

54 When recreational fisheries are managed sustainably, they function as a
55 conservation tool rather than a threat to fish populations [8,9]. For example, recreational
56 fisheries can monitor fish populations by collecting a standard suite of quantitative and
57 qualitative data on the fish caught [9]. To evaluate recreational fisheries as a tool to
58 conserve fish populations, it is important that 1) the angling impact is scientifically
59 determined to be negligible, 2) the angling effort is monitored and regulated and 3) the
60 condition of a fish population is continually determined by a monitoring program [8].

61 Miyabe charr *Salvelinus malma miyabei* is an endemic subspecies of the Dolly
62 Varden that only inhabits Lake Shikaribetsu and its inlet streams, Japan [10]. Miyabe

63 charr is a popular target for recreational anglers because of its beautiful appearance.
64 Since Miyabe charr spawn in inlet streams from September to November, inlet streams
65 of Lake Shikaribetsu are designated as fishing prohibited area by ordinance [11]. Thus,
66 anglers target Miyabe charr in the lake during their feeding migration.

67 Since 1969, the Shikaoi town government has tried to use the Miyabe charr stock as
68 a recreational resource[11]; however, the stock has declined due to recreational
69 overfishing because they were not managed properly in the 1970s [12,13]. To facilitate
70 the sustainable use of Miyabe charr as a recreational fisheries target, their management
71 was entrusted to the non-profit organization 'Hokkaido Tourism Union' and the
72 recreational fisheries management program 'Great Fishing in Lake Shikaribetsu' (GFS),
73 initiated in 2005. Under this program, angling is only permitted for 50 days of the year,
74 to only 50 persons/day and fishing gear is restricted. In addition, catch-and-release is
75 required for all Miyabe charr and anglers are required to submit a daily catch report that
76 describes the species and size of the fish caught and its capture location. These
77 regulations were aimed at not only reducing fishing mortality, but also constructing a
78 monitoring system of the Miyabe charr population using angler data.

79 In Lake Shikaribetsu, recreational fishers should be allowed to take on a role in the
80 conservation of endemic Miyabe charr given that they had once been the reason for their
81 endangered status. In order to achieve this goal, a scientific assessment is needed to
82 evaluate angling mortality and the current state of the Miyabe charr population using
83 angling data. Here this paper reports on a scientific assessment of the Miyabe charr
84 population and determines whether recreational fisheries in Lake Shikaribetsu can be
85 used in their conservation. First, a tag-and-release experiment was performed with
86 recreational anglers to estimate the size of the Miyabe charr population. Second,

87 catch-and-release mortality was estimated to evaluate the angling impact on the Miyabe
88 charr population. Finally, long-term trends in their population levels were estimated by
89 analysing the daily catch reports of recreational anglers over an 8-year period. Based on
90 these results, a scientifically acceptable recreational fisheries management program was
91 assessed as a conservation tool for endemic fish populations.

92

93 **Materials and methods**

94 **Study site**

95 Lake Shikaribetsu is located in the mountainous area of central Hokkaido Island,
96 Japan, at a latitude of 45.3° N and longitude of 143.1° E (Fig. 1). Its area is 3.4 km² and
97 average depth is 56.1m [14]. The lake has three small inlet streams and one outlet
98 stream, but outlet stream was dammed in 1953 to regulate the water level [10]. Lake
99 Shikaribetsu contains masu salmon *Oncorhynchus masou* and rainbow trout *O. mykiss*,
100 both of which were introduced [15], and are targeted by recreational anglers.

101 The fishing season of 50 days per year is divided into two seasons: early June to
102 early July, called the ‘first stage’ (approximately 33 days), and late September to early
103 October, called the ‘second stage’ (approximately 17 days). In addition, the northern
104 part of the lake and all of its inlets are designated as no-fishing areas throughout the
105 year [16](Fig. 1). Angling gear is also restricted to only lure or fly fishing, one fishing
106 rod per person and only one single barbless hook per a rod can be used.

107 In addition to these fishing gear restrictions, anglers also required reporting their
108 daily all catch to submit catch report sheet by fishing regulation. In catch report sheet,
109 anglers report about species, size and capture place of all individuals that they captured.
110 Anglers can approach to Lake Shikaribetsu through only one way-in, which enables

111 stock manager to collect catch report sheet from all anglers.

112

113 **Life history of Miyabe charr**

114 Miyabe charr has two types of life history: the lake-run type and stream-resident
115 type [10]. Lake-run fish usually inhabit the lake and feed mainly on zooplankton [15,17].
116 During September–November, mature lake-run fish migrate to inlet streams and spawn,
117 after which they return to the lake and start their feeding migration again [10]. On the
118 other hand, stream-resident group live their entire life in stream [10,15]. Thus,
119 recreational anglers target adult lake-run Miyabe charr during their feeding migration
120 and immature fish that remain in the lake during the spawning season. In the open
121 fishing area, anglers from onshore or on boats target Miyabe charr. Since the shoreline
122 where angling from onshore is allowed is away from way-in, all anglers have to rent or
123 bring their boat regardless they are going to angle from onshore or on boat. Thus,
124 on-boat angler and onshore angler are indistinguishable.

125

126 **Tagging study of Miyabe charr**

127 A tag-and-release experiment was conducted over the first 10 days of the first stage
128 season from 7 to 16 June 2014. Once fish were caught and the hook was removed, the
129 fish were anaesthetized using 2-phenylethanol and the fork length (FL) was measured. A
130 red, yellow or blue numbered anchor tag (35 mm, Toska-Bano'k Co., Ltd., Tokyo) was
131 attached to the base of the dorsal fin; the tag colour represented the capture site. The
132 tagged fish were released at their point of capture (Table 1, Fig. 2), after their recovery
133 from anesthesia [7]. All angled Miyabe charr were tagged-and-released except for
134 severely injured fish (5 fish). FL of tagged fish was 272 ± 28.4 mm (mean \pm SD).

135 To obtain recapture reports of tagged fish from anglers, recapture report sheets
 136 were distributed to anglers with their licence tickets and catch report sheets. When
 137 tagged fish were recaptured, the anglers recorded their length, recapture position, tag
 138 number and colour on the recapture report sheet and then released them.

139

140 **Estimation of population size based on tagging and angling data**

141 To estimate the population size based on tag-and-release data, tagging mortality and
 142 tag loss were assumed negligible [18]. In our study, a pen experiment was conducted
 143 using tagged Miyabe charr to assess the validity of these assumptions. Nine or ten
 144 Miyabe charr were caught, tagged and kept in a pen (37 cm long × 52 cm wide × 30 cm
 145 high) and the same number of untagged Miyabe charr were kept in an alternative pen as
 146 a control. The pen experiments were conducted with experimental periods of 24 h (4
 147 trials using a total of 39 fish) and 17 days (1 trial using 10 individuals). FL of tagged
 148 Miyabe charr was 277 ± 29.1 mm and 268 ± 34.4 mm for the control. Severely injured
 149 fish was also excluded from pen experiment following tagging study. In addition,
 150 natural mortality during first stage was also assumed negligible because natural
 151 mortality of adult Miyabe charr occur mainly after spawning [19].

152 The population size was estimated using the Schnabel method with an adjustment
 153 for the small sample size as follows [18]:

154

$$N_f = \frac{\sum M_i n_i}{(\sum m_i) + 1} \quad (1)$$

$$SE = N_f \sqrt{\frac{1}{\sum m_i + 1} + \frac{2}{(\sum m_i + 1)^2} + \frac{6}{(\sum m_i + 1)^3}} \quad (2)$$

155

156 where N_f is the population size of the first stage, M_i is the total number of
157 tagged-and-released fish on day i , m_i is the number of recaptured tagged fish on day i
158 and n_i is the total number of fish caught by a recreational angler on day i . 95%
159 confidence interval (95%CI) was also calculated as follows:

160

$$N_f - 1.96 \times SE < N_f < N_f + 1.96 \times SE \quad (3)$$

161

162 **Validation of estimated population size**

163 To assess the accuracy of the estimated population size, population size in first
164 stage was also estimated using recapture data during second stage, under the assumption
165 that tagging ratio at second stage was equal to that in first stage. estimated population
166 size using data during second stage N_f' was calculated as follows:

167

$$N_f' = \frac{(M_f + 1)(n_s + 1)}{(m_s + 1)} \quad (4)$$

$$SE = \sqrt{\frac{(M_f + 1)^2(n_s + 1)(n_s - m_s)}{(m_s + 1)^2(m_s + 2)}} \quad (5)$$

168

169 where M_f is total number of taged-and-released fish during the first stage, n_s is total
170 number of fish caught by recreational anglers in the second stage, and m_s is total
171 number of recaptured tagged fish during the second stage. The result of equation (4)
172 was compared with that of equation (1) to assess the accuracy of the estimated

173 population size.

174

175 **Estimation of catch-and-release mortality**

176 Catch-and-release mortality was assumed caused by hooking injury. Generally, it is
177 classified as immediate mortality (<24 h), short-term mortality (24–72 h), and long-term
178 mortality (> 72 h), according to the time at which mortality occurred after release [20].
179 To estimate the immediate hooking mortality, we counted the number of Miyabe charr
180 that died prior to release (458 fish). Short-term tagging mortality was estimated using
181 the result of the control group in the pen experiments. Since it is known that most
182 hooking mortality occur just after hook removal for charr *Salvelinus* sp. [21], only
183 immediate and short-term mortality was examined as hooking mortalities in Miyabe
184 charr in our study.

185

186 **Standardized CPUE and estimation of population trends**

187 A standardized CPUE was used to estimate changes in the population size of
188 Miyabe charr in order to avoid potential bias due to environmental factors. Angler data
189 (catch and number of daily anglers) were obtained from the catch report sheets collected
190 by GFS staff between 2007 and 2014. In addition, surface water temperature, weather
191 and wind speed data were included in the analysis, all of which were collected by GFS
192 staff at the same time and location every day during the open season for the 8-year
193 period. Weather and wind force were recorded as categorical data (weather:
194 sunny/cloudy/rainy; wind: weak/little/strong). The relationship between Miyabe charr
195 CPUE and these factors was then analysed using a generalized linear model with a
196 negative binomial distribution. Model selection was performed on the basis of Akaike's

197 information criterion (AIC). The model with the lowest AIC value was considered the
198 best model, and any models whose AIC value was within 2 to the best model were also
199 considered to be substantially supported models [22]. The following variables were
200 included in the model:

201

$$Catch \sim Anglers \{ \exp(Year + W. Temp + Weather + Wind) \} \quad (6)$$

202

203 where *Catch* is the daily total catch of anglers, *W. Temp* is the surface water temperature
204 and *Anglers* is the number of daily recreational anglers. Data from the first and second
205 stages were analysed separately because the abundance of fish during the second stage
206 would be much lower since it coincides with the spawning season.

207

208 **Results**

209 **Tagging study on Miyabe charr**

210 A total of 310 Miyabe charr were tagged and released in the first 10 days of the first
211 stage in 2014, nine of which were recaptured during the first stage at a rate of 0–2
212 fish/day (Table 2). In the first stage, four of these recaptured fish could not be identified
213 because their tag number was not reported. The identified five recaptured fish in the
214 first stage had moved in various range in the lake (Fig. 3). During the second stage, two
215 tagged fish were also recaptured, one of which could not be identified.

216

217 **Estimation of population size in 2014 based on tagging and angling reports**

218 In the pen experiments using tagged fish, no tag-associated mortality nor lost tags
219 were observed during the 24-h or 17-day containment (Table 3), and no mortality was

220 observed in the control fish during any of the experimental periods. Therefore, tagging
221 mortality and tag loss were assumed to be negligible in our study.

222 The number of captured, tagged-and-released, and recaptured fish that were used
223 in the population size estimate are summarised in Table 2. The recreational catch ranged
224 from two to 636 fish/day and the total catch was 4,865 fish in 33 days of the first stage
225 in 2014. Thus, the population size of Miyabe charr in June 2014 was estimated to be
226 $105,300 \pm 37,400$ (mean \pm SE) fish. (95% CI: 37,300–178,600)

227

228 **Validation of estimated population size**

229 During the second stage, anglers caught 998 Miyabe charr and two tagged fish
230 were recaptured. As a result, population size was calculated as $103,600 \pm 51,700$ (mean
231 \pm SE) fish. This result was similar to the result of equation (1).

232

233 **Estimation of catch-and-release mortality**

234 The catch-and-release mortality of Miyabe charr was estimated to be 1.8% (95%
235 CI: 0.8–3.4%). Eight of the 458 fish died shortly after capture. However, no mortality
236 was observed throughout the rest of the experimental period (Table 3). Thus, during the
237 first stage in 2014, angler-associated mortality was estimated to be 88 (95% CI: 39–165)
238 of the 4,865 fish caught, which is $<0.1\%$ of the estimated population size.

239

240 **Standardized CPUE and estimation of population trend**

241 The best model for predicting CPUE included surface water temperature and
242 weather conditions as explanatory variables for both the first and second stages (Table
243 4). Standardised CPUE was calculated using the best model with the following

244 conditions: water temperature = 12 °C and weather condition = sunny. These were
245 assumed standardised conditions. The standardised CPUE ranged from 3.6 to 14.3
246 fish/angler-day in the first stage (Fig. 4a) and from 0.9 to 2.4 fish/angler-day in the
247 second stage (Fig. 4b).

248 In the first stage, population was estimated as increasing trend during 2007–2014.
249 In the second stage, the standardised CPUE fluctuated between 2007 and 2014 and was
250 much lower than that during the first stage (Fig. 4), mainly due to the spawning
251 migration to inlet streams. On the other hand, the total angler catch of Miyabe charr
252 consistently increased over the 8-year period in both the first and second stages (first
253 stage: $r = 0.88$, $t = 4.53$, $P = 0.004$; second stage: $r = 0.73$, $t = 2.60$, $P = 0.041$; Fig. 4c,
254 d). Overall, standardized CPUE was stable or increasing although total catch was
255 increasing consistently.

256

257 **Discussion**

258 Our study demonstrated a population assessment of endemic Miyabe charr using
259 angling data. As a result, Miyabe charr recreational fisheries was assessed that it has
260 been worked properly as a conservation tool of endemic fish populations under the
261 current management program. First, angling had a negligible impact on fish populations
262 because angling mortality was very low. Second, the current management program
263 precisely checks and regulates angling effort. Third, the fish population was always
264 monitored using angling data. In conclusion, Miyabe charr recreational fisheries in Lake
265 Shikaribetsu should be encouraged to get involved in the conservation of this endemic
266 fish population under the current regulations.

267 The population size of Miyabe charr was estimated to be 105,300 fish (95%CI:

268 37,300–178,600) in June 2014. This result was much higher than the previous
269 estimation to be 13,880 fish (95% CI: 9,919–23,110) in 1995 and that to be 31,635 fish
270 (95% CI: 21,708–58,291) in 1996 using a tagging method with a gillnet survey [23,24].
271 Although 120,000 Miyabe charr were harvested by anglers in 1979 [25], nowadays, the
272 population size is higher than that recorded in 1995 and 1996, even if comparing lower
273 limit of 95%CI of estimation population size in 2014. Furthermore, the standardised
274 CPUE showed an increasing trend during 2007–2014 (Fig. 4) although total catch was
275 increasing continuously, and fishing mortality was negligible. The standardised CPUE
276 in the second stage was much lower than that in the first stage as the latter coincided
277 with the spawning season of Miyabe charr [10], and thus, most of the mature fish were
278 absent from the fishing area. Thus, recreational angling in Lake Shikaribetsu under the
279 present regulations can be considered as sustainable fisheries management.

280 The hatchery program, which was carried out by Shikaoi town government, was
281 thought to be ineffective to the population trends of Miyabe charr as far as the period of
282 observation of the current study. During 2002–2011, approximately 130,000–245,000
283 yearling Miyabe charr were released into the lake per year. Since Miyabe charr targeted
284 by anglers are mainly 4 or 5 year fish, number of released fish reflect population after 3
285 or 4 years. However, population trend during 2007–2014 was increasing despite number
286 of released fish was slightly decreasing during 2004–2011 (Shikaoi town government,
287 unpubl. data, 2016). After 2012, number of released fish was dramatically decreased to
288 79,186, thus continuing monitoring of Miyabe charr population after 2016 would detect
289 the contribution of hatchery program.

290 Based on the findings of this study, the size of the Miyabe charr population is
291 increasing and fishing mortality is negligible. It is believed that the fishing regulations

292 have contributed to the recovery and sustainability of this endemic population. These
293 regulations state that only lure or fly fishing using a single barbless hook is allowed in
294 Lake Shikaribetsu, all of which have been well known to reduce hooking mortality in
295 catch-and-release fisheries [5,6,26,27]. Hooking mortality of Miyabe charr was
296 estimated to be 1.8% in our study, which was close to the result of previous study using
297 anadromous Dolly Varden that was estimated to be 1.7% [28]. Thus, the present
298 regulations have been effective in maintaining fishing mortality at a low level. This
299 supports the previous finding that catch-and-release is an effective management
300 approach for the sustainable use of white-spotted charr *S. leucomaenis* [21,29,30].

301 The tag-and-release method requires five main assumptions. The assumptions are
302 as follows; 1) tagging mortality and tag loss does not occur, 2) all tag recaptures should
303 be reported, 3) the study population is closed and no emigration nor immigration, 4)
304 tagged fish and untagged fish have equal chance to be caught by anglers, and 5)
305 vulnerability for angling is same for tagged and untagged fish [18].

306 First, tagging mortality and tag loss was confirmed by our pen experiments and
307 was negligible. The second assumption was also confirmed because all anglers have to
308 submit report sheets to GFS staff directly, including tag-recapture information. In
309 addition, since anglers can approach to Lake Shikaribetsu through only one way-in,
310 manager can collect catch report sheet from all anglers due to these geographical
311 characteristics, although it is usually difficult to obtain the data about catch by anglers
312 in other lakes [31].

313 Third, Lake Shikaribetsu can be assumed as a closed system during the study
314 period. The estimation of fish population size was carried out on June, outside of the
315 migration season from the lake to inlet streams [10]. In addition, the Miyabe charr stock

316 is constructed of plural cohorts [23,24]. Furthermore, study period was 33 days, which
317 was short for recruitment to fishing size (250 mm FL). These conditions weaken the
318 effect of recruitment for estimated population size. Therefore, the recruitment and
319 immigration can be assumed negligible.

320 Fourth, tagged fish and untagged fish assumed to have equal chance to be caught by
321 anglers because of our study design and dispersal of tagged fish. The tag-and-release
322 procedure was conducted over as wide area as possible (Fig. 2). In addition, recaptured
323 tagged fish were moved in various range in the lake (Fig. 3), mainly because lake-run
324 Miyabe charr migrate all around the lake with feeding on plankton [17].

325 Fifth, the vulnerability to angling also would be the same between tagged and
326 untagged fish. For white spotted charr, it is known that the angled experience was not
327 related to angling vulnerability [29,30].

328 The sample size affect to the precision of estimated result. In our study, only nine
329 tagged fish were recaptured, which seemed small. However, similar value was obtained
330 when data in second stage was used to estimate population size in first stage. Therefore,
331 our results have substantial meaning for stock assessments.

332 The two ecotypes is known for Miyabe charr, migration group and
333 inshore-colonized group [17]. In this study, inshore-colonized group seem to be caught
334 with migration group (Fig. 3). Considering such condition, both type of Miyabe charr
335 are tagged without distinction. Thus, estimated population size in this study includes
336 both type of Miyabe charr.

337 Cowx et al. [3] proposed some criteria for when anglers could contribute to the
338 conservation of a fish population; 1) management scales are small, 2) threat to
339 conservation originate from outside the fisheries sector, and 3) ecological awareness for

340 the conservation problem is high. In the case of Lake Shikaribetsu, all of these criteria
341 were met. First, Lake Shikaribetsu is small at only 3.4 km², in addition, it has only one
342 way-in. Second, Habitat disturbance of inlet stream and/or environmental pollution of
343 lake system can also be threat for Miyabe charr, both of them are outside of fisheries. In
344 such case, monitoring research with anglers would be able to sense population decline
345 at once. In addition, introduced species (masu salmon and rainbow trout) may become
346 threat for Miyabe charr. In this case, introduced species are also monitored since catch
347 of these species by anglers are also reported. In fact, CPUE of these species are lower
348 than that of Miyabe charr during 2007–2014 in first stage (masu salmon: 0.7–3.2
349 fish/angler-day, rainbow trout: 0.2–0.4 fish/ anger-day, Yoshiyama T, unpubl. data,
350 2016), although catchability is quite higher than Miyabe charr. These results indicates
351 that Miyabe charr is dominant to introduced species now. Monitoring by anglers can be
352 available not only for conservation target but also for introduced species. Third, a
353 consciousness of the conservation of Miyabe charr is high among all anglers because
354 most anglers know that Miyabe charr only inhabits Lake Shikaribetsu [16]. Indeed,
355 anglers are required to submit daily catch reports for stock monitoring, which may
356 further enhance their awareness of the need for conservation. All of these factors should
357 contribute to harmonising recreational fisheries and the conservation of endangered fish
358 populations. Recreational fisheries give high social and economic value for fish
359 population [32], and they should enhance the conservation of an endemic fish species
360 under sustainable management [8]. Thus, recreational fisheries under an appropriate
361 management program should be useful as a monitoring tool, since they provide not only
362 effort for the research, but also a social and economic value.

363 To conserve an endemic species inhabiting a limited area such as the Miyabe charr,

364 prohibiting fishing would be the usual conservation tool. However, Miyabe charr
365 recreational fisheries indicate that, under a sustainable management program,
366 recreational fisheries can be used as an alternative conservation tool. It should be noted
367 that even if angling for an endemic species were prohibited, scientific stock assessments
368 would still be needed for their conservation, which would require significant effort and
369 financial resources. In addition, it would be hard to watch unregulated fishing due to
370 effort and/or financial resource. On the other hand, the use of the fish stock as a
371 recreational fishing target in combination with an appropriate management program
372 should enable population assessment with less effort and cost than long-term academic
373 studies would incur. Furthermore, recreational fisheries under appropriate management
374 can work as a deterrent for unregulated fishing due to their own self and peer
375 monitoring of anglers [9]. For successful recreational fisheries as a conservation tool, it
376 should be important to enhance awareness for conservation of fish population among
377 anglers [3,33]. Miyabe charr angling in Lake Shikaribetsu is a good example
378 demonstrating that recreational fisheries programs can conserve an endemic fish
379 population effectively rather than prohibiting fishing altogether.

380

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388

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478

479 **Table 1** Summary of tagged-and-released Miyabe charr *Salvelinus malma miyabei* at
 480 each site

Date	Released site (Fig. 2)	Tag colour	Number of released fish
June 7	a	Red	50
	c	Red	49
June 8	a	Red	18
	d	Yellow	65
	e	Blue	4
June 9	g	Yellow	12
June 10	j	Yellow	10
	g	Blue	2
June 11	a	Blue	5
	h	Blue	15
	i	Blue	8
June 12	h	Blue	5
	i	Blue	46
June 14	a	Red	3
June 16	f	Blue	19
Total			310

481 The released site symbol corresponds to that in Fig. 2

482

483 **Table 2** Summary of the tag-and-release data on Miyabe charr in 2014

Date ^a	Total catch by anglers	Tagged and released fish	Total tagged and released fish	Recaptured tagged fish
June 7	636	99	-	-
June 8	452	84	99	0
June 9	388	12	183	0
June 10	322	14	195	1
June 11	313	28	209	0
June 12	313	51	237	0
June 14	375	3	288	0
June 15-16	707	19	291	4
June 17–July 7	1,359	0	310	4
Total	4,865	310		9

484 Research and angling on June 13 were cancelled due to a strong storm

485

486 **Table 3** Summary of the pen experiments used to assess tagging mortality in Miyabe

487 charr *Salvelinus malma miyabei*

488

Trial		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Containment period		24 h	24 h	24 h	24 h	17 Days
Tagged	Number of fish	10	9	10	10	10
	Number of dead fish	0	0	0	0	0
Control	Number of fish	10	9	10	10	10
	Number of dead fish	0	0	0	0	0

489

490 **Table 4** The best models for predicting CPUE based on the Akaike's information
 491 criterion (AIC) value

492

493 (a) First stage

Models	AIC	delta
Intercept + <i>Year</i> + <i>W. Temp</i> ^a + <i>Weather</i>	2214.0	-
Intercept + <i>Year</i> + <i>W. Temp</i> + <i>Weather</i> + <i>Wind</i>	2215.7	1.75

494

495 (b) Second stage

Models	AIC	delta
Intercept + <i>Year</i> + <i>W. Temp</i> + <i>Weather</i>	866.9	-
Intercept + <i>Year</i> + <i>Weather</i>	867.6	0.70
Intercept + <i>Year</i> + <i>W. Temp</i>	868.9	1.97

496 ^a *W. Temp*, surface water temperature

497

498 Figure captions

499

500 **Fig. 1** Location of Lake Shikaribetsu and angling regulations. Inlet streams and the
501 northern part of the lake were designated as fishing prohibited areas

502

503 **Fig. 2** Tag-and-released sites in open area. The number of tagged-and-released fish at
504 each site was provided in Table 1

505

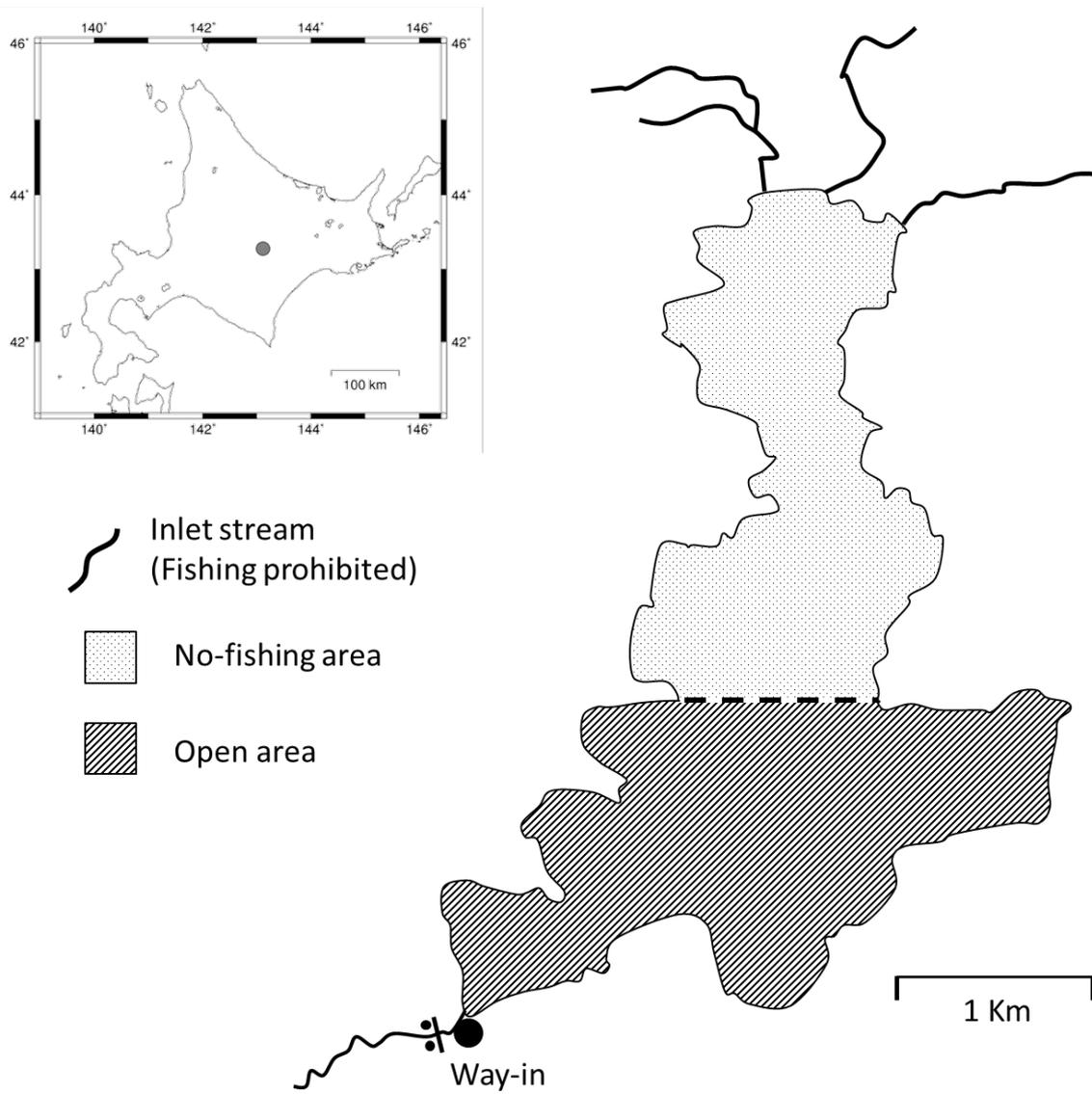
506 **Fig. 3** The movement of individually marked Miyabe charr. The tag number (#) and
507 interval between the mark and recapture are shown. Number 390 (dotted line) was
508 recaptured during second stage

509

510 **Fig. 4** Time series of standardised CPUE and total catch of Miyabe charr, *Salvelinus*
511 *malma miyabei*, during 2007–2014 in (a) the first stage and (b) second stage. The
512 change in total anglers' catch in (c) the first stage and (d) second stage

513

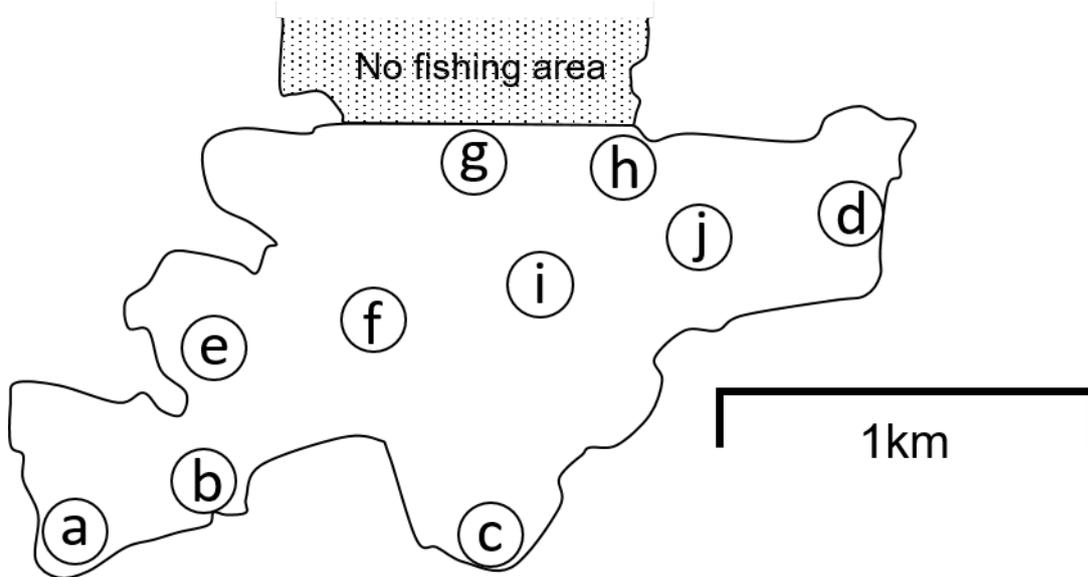
514 Figures



515

516 **Fig. 1**

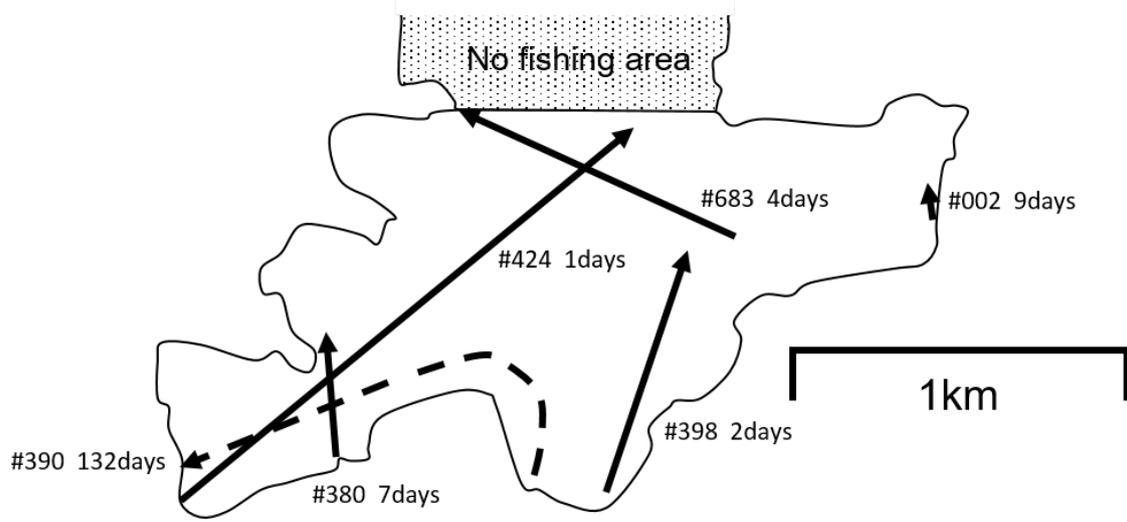
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518

519 **Fig. 2**

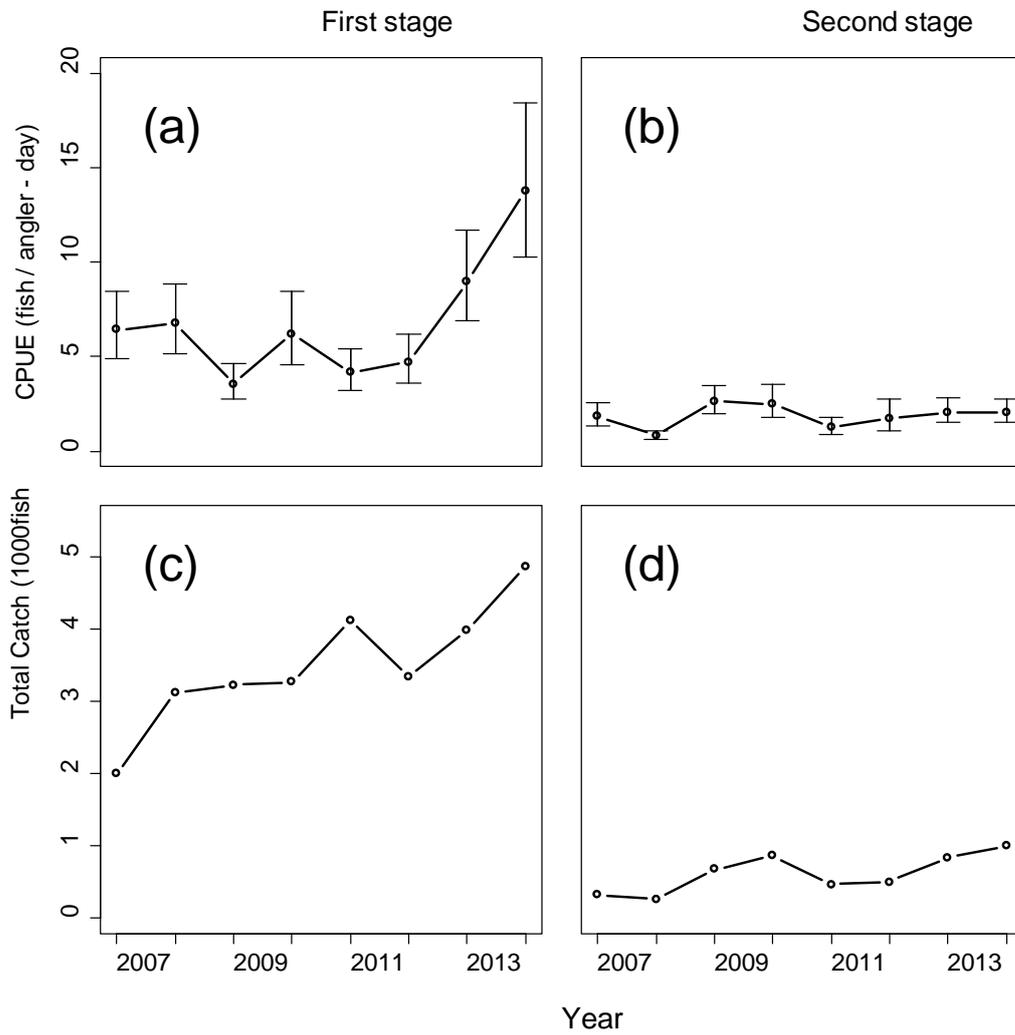
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521

522 **Fig. 3**

523



524

525 **Fig. 4**

526