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MODELING SPAWNING DATES OF *HUCHO TAIMEN* IN MONGOLIA TO ESTABLISH FISHERY MANAGEMENT ZONES

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Abstract. The ecological impacts of recreational fisheries are of growing concern and pose a number of unique management challenges. Here we report on our efforts to provide guidance for managing a recreational fishery for taimen, the giant Eurasian trout (*Hucho taimen*) in Mongolia. This species has declined dramatically across its range of Siberia and Central Asia, and is currently listed as endangered in Mongolia. Strong populations persist in remote regions of Mongolia because of limited anthropogenic impacts and harvest, though interest in the fishery is expanding rapidly. Current fishing regulations list the spring "opening date" for taimen fishing as 15 June, although regulations have not been consistently enforced, partially because taimen spawn much earlier than 15 June in much of the country. Through a combination of statistical models, climate data, knowledge of taimen biology, and geographic information systems (GIS), we model taimen spawning dates for potential habitat in Mongolia. A parametric bootstrap procedure was used to simulate variability in spawning date derived from inter-annual climate variability and model error, from which we estimated the date in which taimen spawning is predicted to occur with 90% confidence. We recommend the designation of three fisheries management zones, with corresponding opening dates of 20 May, 1 June, and 15 June. Our fishery opening date recommendations are less restrictive than existing regulations. Provided there is little or no catch-and-release fishing mortality, this approach serves both environmental and human needs by protecting taimen during the reproductive period, while still allowing a post-spawning catch-and-release fishery that benefits local economies and generates revenue (through fishing concession fees) for local conservation efforts.

Key words: conservation; geographic information system; fisheries; Hucho taimen; *management; Mongolia; salmonid; spawning date.*

Introduction

Commercial overfishing has been widely documented in both marine and inland environments (Hilborn et al. 2003, Allan et al. 2005), with important consequences for aquatic biodiversity, ecosystem function, and the provision of ecosystem goods and services. Only recently has the broader ecological consequences of recreational fishing been recognized (McPhee et al. 2002, Post et al. 2002, Coleman et al. 2004, Cooke and Cowx 2004, 2006). From a regulatory perspective, recreational overfishing is difficult to prevent because recreational fishing regulations typically limit the harvest rates of individual anglers through bag limits, gear restrictions, and the establishment of protected areas, rather than restricting total fishery harvest (Cooke and Cowx 2006). It is clear that innovative approaches to managing recreational fisheries are needed; this is especially the case in developing countries, where overfishing is poorly documented, but may be pervasive (Allan et al. 2005).

Catch-and-release fisheries can be compatible with the conservation of fisheries resources, provided that populations are fully protected during the reproductive period, and that there is little or no post-release mortality (Cooke and Suski 2005, Cooke et al. 2006). Under these conditions, establishment of catch-and-release fisheries can provide a win-win scenario: economic benefits can continue to derive from a fishery, while simultaneously sustaining the fishery resource (Cooke and Suski 2005). In this paper, we describe the first step in our broader efforts to institute a sustainable fishery for taimen (*Hucho taimen*) in Mongolia through the use of regional fishing opening dates for a catch-and-release fishing concession system. Taimen are the world's largest species of salmonid, attaining more than 2 m in length and 100 kg in mass (Holcik et al. 1988,

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Matveyev et al. 1998). As the apex predator in Siberian river ecosystems, the species is slow-growing, long-lived, and naturally resides at low population densities (Holcik et al. 1988, Matveyev et al. 1998), thereby making the species highly vulnerable to overfishing.

This species was historically widespread in the Volga/Caspian, Arctic, and Pacific drainages of northern Eurasia, a region encompassing vast territory of the Russian Federation and parts of Kazakhstan, Mongolia, and China, but has suffered dramatic population declines and local extirpations due to rampant logging, poaching, dam-building, and pollution (Holcik et al. 1988, Matveyev et al. 1998). Much of Mongolia is non-industrialized, and retains a traditional culture of nomadic pastoralism. The capture and consumption of wild fish is not an important part of traditional Mongolian culture. Consequently, some of the more remote Mongolian rivers still support healthy taimen populations, thus providing a conservation opportunity for both taimen and Mongolia's river ecosystems. Since the collapse of the former Soviet Union in 1990, Mongolia has undergone democratization and partial economic privatization. Tourism has emerged as an important source of foreign currency, and offers an economic alternative to activities such as gold mining and heavy industry. The number of private tourist companies offering taimen fishing has increased in recent years, attracting anglers from around the world. The current upsurge of taimen fishing and harvest in Mongolia could lead to population collapse, undermining not only the fishery, but the long-term ecotourism potential of the fishery. We believe that there still remains a window of opportunity to enact sensible and protective fisheries regulations for this species, particularly with regard to harvest policy, fishery opening dates, and the existence and location of protected areas.

Protecting taimen from the disturbance associated with fishing during the spawning period is an important fisheries management goal (Cooke and Suski 2005). Little data exist on taimen spawning ecology in Mongolia, though reports from the high elevation Darhat region (northwestern Mongolia) indicate that taimen spawn some time around 15 June. Correspondingly, the Ministry of Nature and the Environment's nationwide opening date for taimen fishing is 15 June, although enforcement of fishery regulations is minimal. A number of factors such as photoperiod, rate of temperature change, and changes in river flow could trigger spawning (Moyle and Cech 2004), though Holcik et al.'s (1988) detailed summary of the Eastern European and Soviet literature on the biology of taimen indicates that spawning generally commences at water temperatures of 6–8°C. The date in which river water is expected to reach this temperature (referred to hereafter as "estimated spawning date" [ESD]), will undoubtedly vary widely across Mongolia due to the tremendous geographic variation in elevation and latitude. Thus, the current policy of a single opening date across the entire range of taimen in Mongolia is likely not appropriate. In the warmer and low-elevation regions of the country, a 15 June opening date will be overly protective, and place unnecessary constraints upon catch-and-release fishing operations. In colder, high-elevation areas, the current 15 June opening date may not be protective of taimen spawning. The goal of this study is to offer a quantitative basis for designating fisheries management zones that encompass Mongolia's geographic variation and protect taimen from any sort of angling during the reproductive period. Though water temperature data is not widely available for Mongolian rivers, daily air temperature data is collected at meteorological stations around the country. Previous studies have used regression equations to estimate weekly water temperature from weekly air temperature (Stefan and Preudhomme 1993, Pilgrim et al. 1998, Morrill et al. 2005). We combine this approach with Geographic Information Systems (GIS) to estimate taimen spawning dates across Mongolia, and recommend the designation of three taimen management zones with distinct opening dates.

Methods

Air and water temperature data

Our first objective was to produce an air temperature–water temperature regression model that would be applicable to Mongolia. River water temperature can be accurately predicted from air temperature when using weekly averaged data (Stefan and Preudhomme 1993, Pilgrim et al. 1998, Morrill et al. 2005). We collected surface water temperature data for two Mongolian rivers: one field season of water temperature data from the Uur River (Taimen Conservation Fund field research camp, 15 June 2004–27 October 2004) and two field seasons from the Eg River (town of Erdenebulgan, 15 June 2004–27 October 2004 and 17 April 2005–31 October 2005). In 2004, surface water temperature was recorded four times daily (00:00, 06:00, 12:00, and 18:00 hours) with an Onset temperature logger (Onset Computer Corporation, Bourne, Massachusetts, USA). In 2005, data were collected three times daily (08:00, 14:00, 20:00) with a hand-held mercury thermometer.

In 2004, air temperature at the two study sites was recorded three times daily (05:00, 13:00, and 21:00 hours) using an Onset temperature logger. In 2005, daily mean temperature was obtained from the local meteorological service. Daily temperature data were averaged to give weekly mean air and water temperatures (separate estimates for each river and year), producing 76 corresponding weekly air and water temperature observations for developing air-temperature–water-temperature models (model presented in *Results*).

Predicting water temperature and estimated spawning date (ESD)

For each of 51 weather stations in Mongolia and bordering regions in Russia and China, we obtained up to 12 years of the most recent daily air temperature data (ranging from 5 to 12 years, average of 11.5 years of data per site) from the U.S. National Climatic Data Center (data *available online*).[7] Because climate warming has been documented in Mongolia in recent decades (Batima and Dagvadorj 2000, Ma et al. 2003, Punsalmaa et al. 2004), we use this recent climate data to approximate present-day climate conditions, while still incorporating interannual climate variability. For each weather station in each year (51 weather stations, average of 11.5 years of data per station, 589 station–year combinations), we computed mean air temperature for each week spanning weeks 16–29, a period that fully encompasses taimen spawning in Mongolia. Weekly water temperature was then estimated from weekly mean air temperature using the above air-temperature–water-temperature regression model.

For each station, estimated weekly water temperature was regressed vs. "week" for the period spanning weeks 16–29. Estimated weekly water temperature consistently increased linearly as a function of week over this period. The date in which water temperature is predicted to reach 6°C (estimated spawning date [ESD], expressed in weeks) was estimated by solving the linear regression equation

$$\text{week} = \text{slope}(\text{temp}) + \text{intercept}$$

for temp = 6°C for each weather-station–year combination ($n = 589$ combinations). For each weather station, mean (and standard deviation) of ESD was computed, and multiple linear regression was used to model mean ESD as a function of latitude, longitude, and elevation.

Using a digital elevation model (DEM) of Mongolia (U.S. Geological Survey 2002), GIS layers for Mongolian rivers and watersheds (Environmental Systems Research Institute 1993) and knowledge of which watersheds support taimen populations (Ocock et al. 2006), rivers large enough to potentially support taimen populations were identified. These rivers were then divided into segments 500 m in length (approximately 32 000 segments in total) that are hereafter considered potential taimen habitat. Since latitude, longitude, and elevation are known for the middle point of each segment, the multiple regression model was used to estimate ESD for each potential taimen habitat river segment.

The above approach provides a way of approximating ESD for the potential taimen habitat of Mongolia, but does not incorporate error associated with estimating spawning date, specifically (1) error derived from the air-temperature–water-temperature model, approximated as the root mean squared error of the air–water-temperature regression equation, (2) interannual climate variability at a given site, and (3) error associated with predicting ESD at a given site from latitude, longitude, and elevation, again approximated as the root mean squared error of the multiple regression model predicting ESD from these three variables.

To assess these sources of error variance in ESD, and to build in the appropriate safety factors so that regulations are protective of taimen spawning in the majority of years and locations, a parametric bootstrap approach (Elfron and Tibshirani 1993) was used to simulate the variability associated with ESD estimates. Monte Carlo samples of ESD were generated from the series of models described above (air temperature-water temperature model, the water-temperature–ESD model, and the multiple regression predicting ESD from latitude, longitude, and elevation). For each of the ~32 000 potential taimen habitat river segments, we generated a Monte Carlo distribution of 100 ESD values that reflects these three error sources. For each segment, we then computed the adjusted estimated spawning date (ESD_a) as the 90th percentile value of the distribution (i.e., protective of taimen spawning in 90% of years). ESD_a values for the potential taimen habitat river segments were mapped using GIS.

Several methods could be used to divide taimen habitat into management zones based on the computed ESD_a values. We opted to work with existing political units, which is the most practical approach considering that this analysis is intended to be the basis for fisheries management. Aimags (the Mongolian equivalent of states or provinces) are relatively large (average area ~75 000 km^2), and ESD_a values, not surprisingly, can be highly variable within an aimag. Aimags are comprised of soums, a political unit that is equivalent to a county. There was relatively little variation in ESD_a within soums (on average, 1 SD of ESD_a values = 0.29 weeks), thus we opted to conduct the analysis at the soum level. For each soum, the mean ESD_a for all potential taimen habitat river segments was computed. From this soums were classified into one of three taimen management zones with distinct opening fishing dates (20 May, 1 June, 15 June) estimated to be protective of taimen spawning.

Results

Air-temperature–water-temperature model

There were no significant differences in air-temperature–water-temperature regression model slopes and intercepts for the three site–year combinations (ANCOVA; Table 1). Comparison of "warming" and "cooling" period air-temperature–water-temperature models revealed no significant difference between model slopes, though there was a significant difference in model intercepts (Table 1). Because the intercept of the air-temperature–water-temperature relationships differed between warming and cooling periods (Table 1), our model for estimating water temperature was derived from only the spring–summer warming period data (late April to early July; water temperature = 0.734 × air

[7] ⟨www.ncdc.noaa.gov⟩

TABLE 1. Slopes and intercepts from linear regressions of air-temperature–water-temperature models and their significance for the three river–year combinations and for warming vs. cooling periods of the annual temperature cycle.

	Site comparison (n = 76)						Warming vs. cooling (n = 74)				
Parameter	Eg R., 2005	Eg R., 2004	Uur R., 2004	df	F	P	Warming	Cooling	df	F	P
Slope†	0.7045	0.5992	0.7061	2, 70	1.07	0.35	0.73	0.75	1, 70	0.17	0.68
Intercept	2.4859	2.837	2.2943	2, 72	2.20	0.12	0.183	2.064	1, 71	13.29	0.0005

Notes: Data from the three river–year combinations are combined for the temperature cycles. Homogeneity of regression to test for differences in slope and ANCOVA for differences in model intercepts are presented.

† Test of heterogeneity of slopes for covariate in model. A nonsignificant ($P > 0.05$) effect indicates that variable × covariate interactions are negligible (no difference in slopes), allowing direct comparison of model intercepts.

temperature + 0.183, $r^2 = 0.83$, RMSE = 1.68, $P < 0.005$, $n = 22$ weeks, Fig. 1).

Predicting water temperature and ESD

Using the above air–water-temperature equation, weekly water temperature was estimated from weekly air temperature for each of the weather-station–year combinations (n = 589 estimates). Estimated water temperature increased linearly with week over the period spanning week 16–29 (Fig. 2), from which estimated spawning date (ESD) was calculated for each weather-station–year combination. Mean ESD was calculated for each station. Multiple linear regression using latitude, longitude, and elevation explained 87% of the variation in mean ESD (Fig. 3; ESD = 0.006586 × latitude + 0.00108 × longitude + 0.0041 × elevation −29.395, $r^2 = 0.87$, RMSE = 0.44, $P < 0.0001$, $n = 51$ sites).

The parametric bootstrap generated a frequency distribution of estimated spawning dates for each of the ~32 000 river segments considered potential taimen habitat. The mean ESD across all river segments was 15 May, with an average standard deviation at a given point of approximately six days. An example of a bootstrap-generated ESD distribution at a specific site is shown for the river segment nearest to our field site on the Uur River (Fig. 4). ESD (the peak of the frequency distribution) is 14 May. In 2006, our field team observed taimen spawning activity from 16 to 23 May at this site. These dates fall within the predicted distribution of spawning dates (Fig. 4). On the nearby Eg River, we observed spawning activity on 13–16 May, which corresponded with 50–60th percentile values of the bootstrap-generated ESD distribution (not shown). The above comparison indicates that our estimated spawning dates generally correspond with observed spawning dates, though further field validation is needed.

For each of the ~32 000 potential taimen river segments, we computed what we call the adjusted estimated spawning date (ESD_a) from the bootstrapped distributions, which is the date in which taimen are predicted to have spawned with 90% confidence (Fig. 4). We then generated a frequency distribution of the 32 000 ESD_a values (Fig. 5). ESD_a ranged from 2 May in the low-elevation regions, to 28 June in the higher elevation areas (particularly the Darhat region of northwestern Mongolia). GIS was used to project ESD_a values onto a map of Mongolia, and to classify soums (political units equivalent to counties) into three zones, corresponding with opening dates of 20 May, 1 June, and 15 June (Fig. 6).

DISCUSSION

The work described here stems from the growing recognition of the ecological impacts of recreational fisheries (McPhee et al. 2002, Coleman et al. 2004, Cooke and Cowx 2004, 2006, Lewin et al. 2006), and the need for innovative management strategies aimed at managing these growing fisheries to be sustainable in the long term. Such needs are particularly heightened in the developing world, where there is limited biological information and fisheries expertise, and recreational fisheries are expanding rapidly and poorly documented. In such situations, catch-and-release fisheries may offer a valuable conservation strategy. General principles for catch-and-release fisheries have been forwarded (Cooke and Suski 2005), though these authors have also emphasized the limitations of a one-size-fits all approach, and argued for the need for species-specific management approaches (Cooke and Suski 2005).

The model presented here represents such a species-specific approach for the management of taimen, a

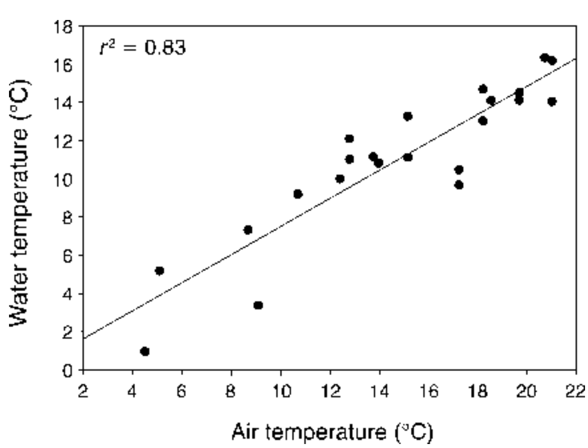

FIG. 1. Relationship between mean weekly water temperature and air temperature for two sites on the Eg and Uur Rivers (2004 and 2005) in northern Mongolia during the spring/early summer warming period. Regression equation: water temperature = air temperature × 0.734 + 0.183, $r^2 = 0.83$, $n = 22$ weeks.

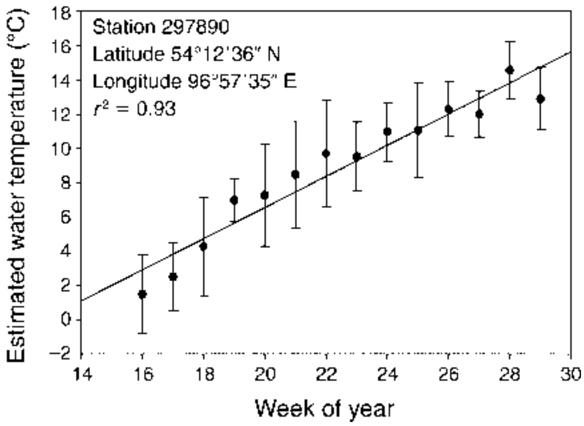

FIG. 2. Mean weekly air temperature vs. week of the year (weeks 16–29; week 1 is first week in January) for a randomly chosen weather station in northern Mongolia. Error bars represent ±SD for among-year (n = 12 years) variation in average weekly temperatures. The other weather stations showed similar linear increases in air temperature as a function of week.

species that comprises an internationally recognized recreational fishery, as well as an important conservation concern due to their endangered status (Mongolian Red List of Fishes, *unpublished document*). Specifically, our analysis uses empirical air-water temperature models and geographic information systems (GIS) to model broad-scale variation in spawning dates for taimen. Air-water temperature models have been previously used to forecast impacts of global climate change on fish population status and distribution (Eaton and Scheller 1996, Rahel et al. 1996, Morrill et al. 2005). This is the first study to use this approach to guide the establishment of fishery opening date regulations, and to account for climate-driven geographical variation in a critical biological process.

This work fills an important void in the fisheries management of Mongolia. Affording protection to taimen during the spring spawning is imperative, as taimen and other salmonids are vulnerable to exploitation and other types of disruption during this period (Holcik et al. 1988, Roberts and White 1992, Matveyev et al. 1998). During spring, taimen form spawning pairs and small aggregations in riffle habitats of mainstem rivers, and are highly active and conspicuous. Poachers are known to target taimen during spawning, and any type of fishing activity could disrupt taimen spawning activity or have impacts on eggs and fry (Roberts and White 1992). At the same time, recreational fishing-based tourism is expanding rapidly. Due to high-flow conditions during summer and a long and ice-covered winter, the taimen fishing season is generally limited to a few weeks in spring (around or just after spawning) and a few weeks in fall (September–October). Reliance on a single opening date for this fishery across all of Mongolia ignores the biological and geographical diversity of the country. Furthermore, current regulations dictate that the country-wide opening date for taimen fishing is 15 June. Our analysis indicates that 15 June represents an extreme outer bound for taimen spawning for the entire country of Mongolia (Fig. 5), with spawning occurring much earlier than 15 June in nearly all (>98%) river segments considered to be potential taimen habitat, even after adjusting for model error and inter-annual climate variability. Current opening date regulations tend to be highly overprotective of taimen during the spawning period. Though this conservative approach is theoretically more protective of the resource, we argue that this one-size-fits-all approach to fishery regulations is both unnecessary and irrational if regional regulations based on the biology of the species can be developed. This study forwards a regional approach, and is intended to serve as the foundation for improved national fishing regulations that are protective of taimen during the spawning period, while also allowing a controlled post-spawning catch-and-release fishery.

This study highlights some of unique challenges of environmental management in the developing world. One common constraint is the sparse biological data required for improving management practices (Rivers-Moore et al. 2005). For example, there are no systematic data documenting taimen spawning dates, and there are few fisheries biologists for a country of this size. Fortunately, taimen spawning is well documented to be triggered by spring water temperature (Holcik et al. 1988, Matveyev et al. 1998). Water temperature data for Mongolian streams are not generally available, leaving us with the water temperature data from our field research sites to generate the necessary weekly air–water-temperature relationships. Though this empirical relationship was based on data from two sites and two

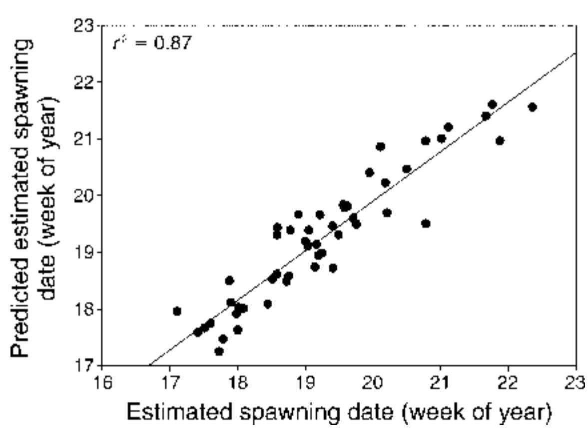

FIG. 3. Predicted ESD vs. ESD (estimated spawning date) for taimen (*Hucho taimen*, giant Eurasian trout). ESD values are from the 51 weather stations used in this analysis and represent the mean date when water temperature is predicted to reach 6°C, derived from air-temperature–water-temperature regressions. Predicted ESD values are from the multiple regression model predicting ESD using latitude, longitude, and elevation for these 51 points.

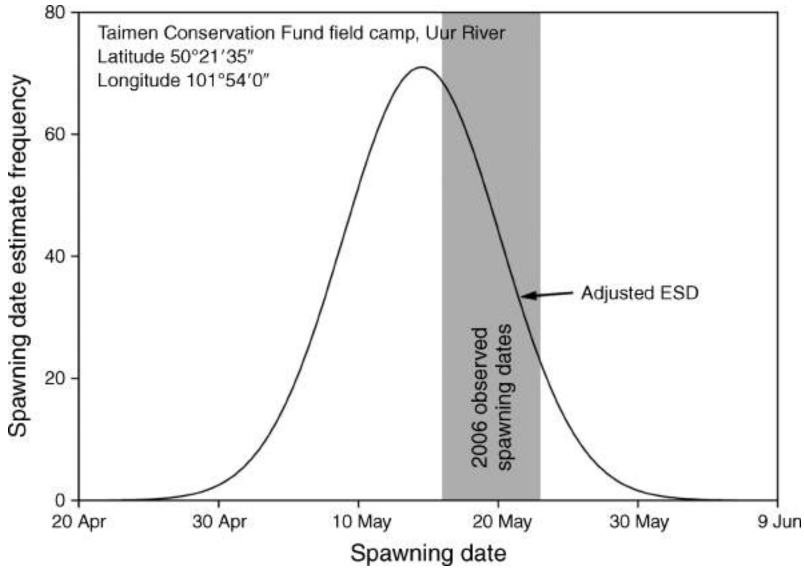

FIG. 4. Distribution of estimated spawning date (ESD) for the Taimen Conservation Fund field camp on the Uur River. Variation around the mean ESD is the result of model error (the air-temperature–water-temperature model and the multiple regression predicting ESD from latitude, longitude, and elevation) and interannual climate variation, simulated through a parametric bootstrap procedure. Observed spawning dates for taimen at this site for 2006 and the adjusted estimated spawning date (ESD_a, protective with 90% confidence) are shown.

years of temperature data, the coefficients from our Mongolia-specific temperature model do not differ appreciably from previous air-water temperature relationships (Crisp and Howson 1982, Stefan and Preud-homme 1993, Pilgrim et al. 1998, Morrill et al. 2005), thus lending generality to this approach.

A central assumption of this analysis is that there is a direct and causal link between the initiation of taimen

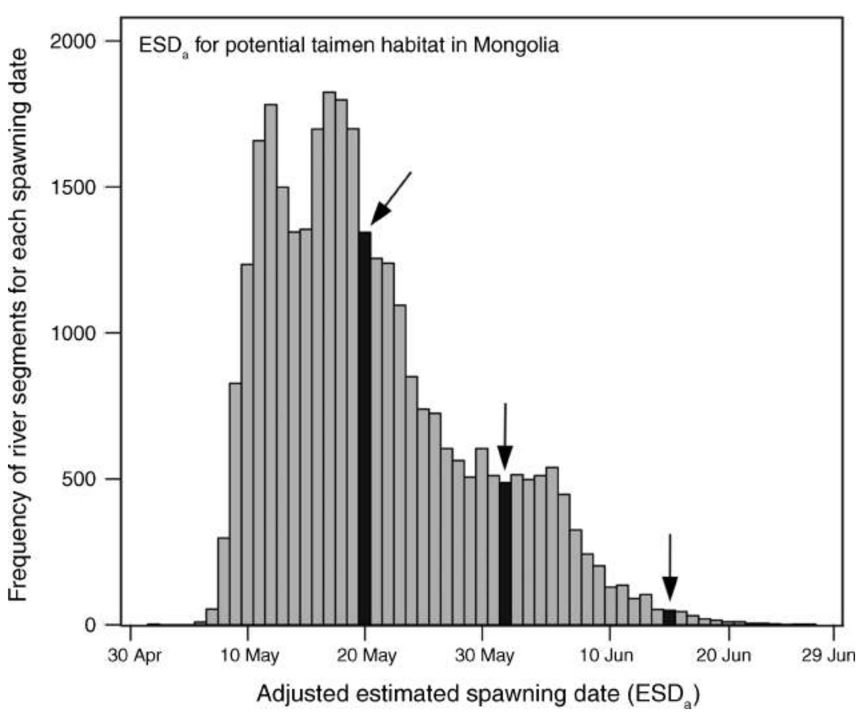

FIG. 5. Frequency histogram showing the distribution of ESD_a (adjusted estimated spawning date, 90% protective) for the ~32 000 river segments in Mongolia considered to be potential taimen habitat. Arrows indicate the cutoffs used to designate the three proposed taimen management zones.

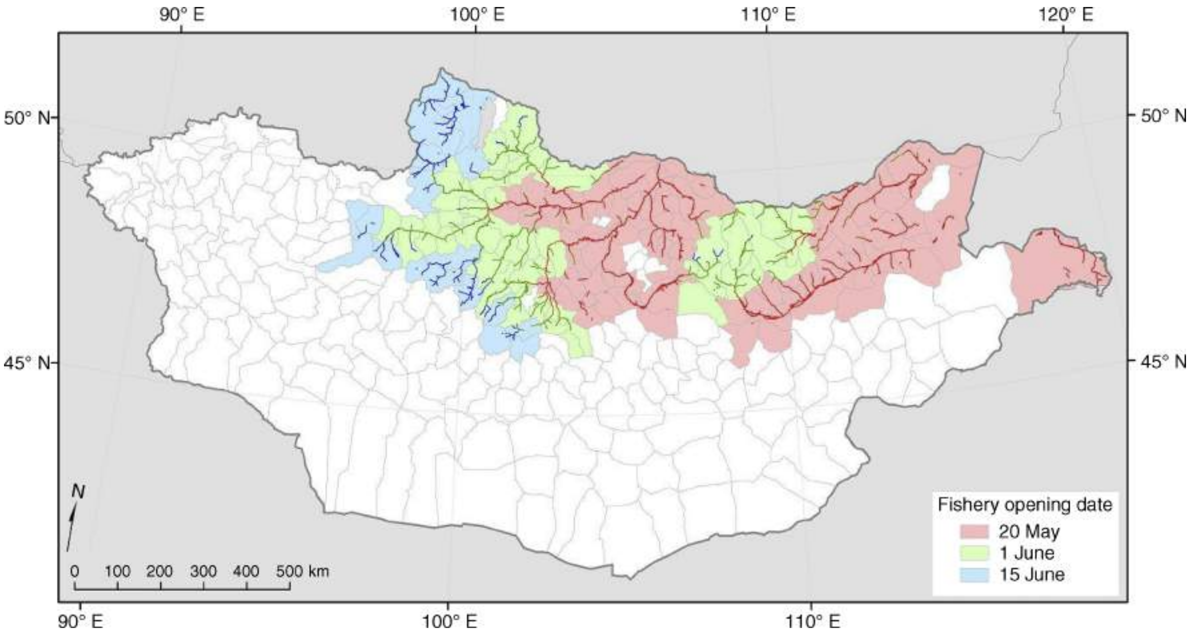

FIG. 6. Map showing the three recommended taimen management zones. Opening dates are 20 May (red), 1 June (green), and 15 June (blue). The political boundaries represent soums (equivalent to counties), which are suitable management units for implementing Mongolian fisheries law.

spawning and spring water temperature. Water temperature is widely recognized as a dominant factor responsible for triggering fish spawning, though other factors such as photoperiod, water flow/discharge, and rate of temperature change may also play a role in determining the timing of reproductive behaviors (Scott and Crossman 1973, Moyle and Cech 2004). Holcik et al. (1988) reviews studies that have examined spawning behavior of taimen, which provides general support for spawning at water temperatures of 6–8°C. This pattern is corroborated by our 2006 spawning surveys in the Eg and Uur Rivers, in which mean daily water temperature at the onset of spawning was 7°C and 8°C, respectively.

It will be essential to provide additional field validation of our taimen spawning date predictions. At present, we have field validation for only two locations near our field camp. At sites on both the Eg and Uur River, observed spawning dates for 2006 fell within the range of estimated spawning dates by our model. Field validation of taimen spawning is labor-intensive, and little information is available about taimen spawning in Mongolia. In some areas, local residents are attentive to taimen spawning. Interviews with local residents may be valuable for validating our model predictions, particularly if several interviewees offer similar spawning dates. While field validation of predicted spawning dates offers a high degree of certainty, it only provides estimates of spawning date at a single site in a single year. Considering the high degree of inter-annual variation in spawning date related to climate variability, interviews with local residents may provide important ground-truthing information across broad geographic areas.

Because our management recommendations are based on relatively limited information, it is imperative that specific regulations based on this work can be updated in light of new studies and information. This could involve reclassifying soums into different management zones in the future based on local conditions, site-specific information, or future updates of the model. In addition, climate warming is expected to cause taimen spawning dates to occur earlier in the season. Thus, spawning date predictions from our study will become increasingly conservative as air temperature increases in the coming decades. While this will have the effect of making our proposed regulations increasingly protective, it could also require policy revisions as climate regimes diverge from the regime upon which this analysis is based.

Our model predicting taimen spawning dates and establishing management zones based on this analysis is part of a larger effort to both protect and valuate this increasingly important fishery. Why then, are we recommending regulations that are less restrictive that existing regulations? Are more restrictive regulations always better? We argue that an important step towards sustainable fisheries management is the designation of regulations that are both sensible and grounded in the biology of the species. Once reasonable regulations are implemented, efforts can be directed to ensuring that regulations are enforced.

While taimen have declined precipitously across most of their range, some of Mongolia's rivers retain reasonably intact populations. It is still early in the development of fishing-based tourism in Mongolia, though international interest in taimen fishing is expanding rapidly. While many recreational anglers practice catch-and-kill practices, a number of commercial outfitters have adopted strict catch-and-release policies, and have been strong advocates for sustainable management of taimen fisheries. Though awareness of the impacts of recreational fisheries is growing (Coleman et al. 2004, Cooke and Cowx 2004, Lewin et al. 2006), our conservation strategy for taimen is generally supportive of controlled catch-and-release recreational fisheries. Catch-and-release angling mortality rates vary widely among published studies (Bartholomew and Bohnsack 2005), though mortality rates tend to be low (<10%) if appropriate fishing and handling techniques are employed. Provided there is little or no post-release mortality, as we believe to be the case with existing taimen catch-and-release fisheries, catch-and-release fishing is likely to have little impact on the long-term viability of fish populations (Whoriskey et al. 2000, Thorstad et al. 2003, Doi et al. 2004).

The situation may provide a unique fisheries conservation opportunity: protecting taimen populations while allowing catch-and-release fly fishing may serve as a vehicle for the conservation of Mongolia's rivers. The urgency of such efforts is increasing: untapped mineral deposits combined with lack of environmental protections has made Mongolia an attractive location for mining development, and foreign investment in large-scale mining (using environmentally devastating placer mining techniques) has already impacted some of Mongolia's rivers, and threatens to impact many more (Stubblefield et al. 2005). By "valuating" a previously unvalued resource, a non-extractive taimen fishery can create incentives for protection of taimen and their habitat. The situation has potential to offer a win-win scenario, whereby improvements in human well-being derive directly from protection of natural resources (Rosenzweig 2003). Towards this end, a Mongolian non-profit organization called Taimen Conservation Fund (TCF), with whom we are partnered, has been forwarding a regulatory structure for natural resource management that promotes controlled catch-and-release fishing as a vehicle for furthering economic development, while at the same time fostering river protection. One of TCF's strategies has been to establish conservation zones to be managed as "fishing concessions," in which rights to catch-and-release fly-fishing is licensed (for a fee) to individual outfitters. Revenue from these environmental service payments are directed to support local community initiatives, and to cover resource management and enforcement costs. These efforts represent an important example of an incentive-based approach to managing fisheries resources for sustainability (Grafton et al. 2006), and may hold potential for reducing resource overexploitation and avoiding the "tragedy of the commons" (Hardin 1968, Ostrom et al. 1999).

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