RIVER RESEARCH AND APPLICATIONS
River Res. Applic. **33**: 578–585 (2017)
Published online 11 January 2017 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/rra.3118

BORDERS AND BARRIERS: CHALLENGES OF FISHERIES MANAGEMENT AND CONSERVATION IN OPEN SYSTEMS

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ABSTRACT

Large rivers often bisect geopolitical boundaries where management goals may be at odds for a shared fishery, creating fragmented management zones. Fragmentation due to physical barriers may further impact the fishery by reducing fish passage. Our goal was to estimate basin-wide parameters (i.e. movement, survival and capture probabilities) of a large-river species known to move throughout watersheds. We tagged13 892 Channel Catfish in the Red River of the North (Red River) and Lake Winnipeg in Manitoba, Canada, and collected 553 recaptures. We estimated 2.2% of catfish are moving from the Red River to Lake Winnipeg each month and 9.4%, primarily large (>600 mm) individuals, moved upstream through a dam (monthly). Approximately 5.6% of catfish moved to the USA each month, and only one fish returned. Our results suggest the lower reaches of the Red River may be a source population for the USA, where survival is lower, and Lake Winnipeg. The complex movements of Channel Catfish throughout the Red River, across barriers and international boundaries, suggest conservation and management of fish populations should be watershed wide. Copyright © 2017 John Wiley & Sons, Ltd.

KEY WORDS: river; fragmentation; fish movement; dam passage; fish management

Received 13 September 2016; Revised 22 November 2016; Accepted 30 November 2016

INTRODUCTION

Rivers traverse long distances that often intersect geopolitical boundaries. Many riverine fish species are also adapted to traverse long distances as part of their life cycle, and those that cross geopolitical boundaries may be subject to different philosophical approaches for population management and conservation if not considered collaboratively (Pracheil *et al*. 2012). While there is no physical barrier as such to block fish movement, the implications could be equally profound if differing approaches do not match the biological capacity of the species. Fragmentation of management within a watershed is especially important should a meaningful proportion of the population move between such jurisdictions with regularity.

Coupled with the potential disconnect associated with geopolitical boundaries are the influence dams have on disconnecting fish from habitats. Habitat fragmentation by construction of dams within larger rivers is common (Nilsson *et al.,* 2005) and has negatively influenced aquatic biota by altering fish assemblages (Taylor *et al.,* 2008; Liermann *et al.,* 2012) as well as preventing fish passage (Santucci *et al.,* 2005; Liermann *et al.,* 2012). Fish movement throughout a river system is important because such behaviour facilitates genetic diversity (Raeymaekers *et al.,* 2009), maintains biodiversity (Perkin *et al.,* 2015) and enables access to habitats necessary to complete life cycles (Sheer and Steel, 2006). As such, habitat fragmentation can also influence population dynamics at multiple spatial and temporal scales (Fullerton *et al.,* 2010). Crucial habitat components, such as spawning and overwintering areas, may not be evenly distributed throughout a watershed, and isolation from these habitats could have negative consequences for individuals or their offspring that are not able to access them. Therefore, the predictability of fish movement within a watershed may very well depend on the availability and spatial arrangement of habitats (Dunning *et al.,* 1992; Schlosser and Angermeier, 1995) as well as the ability to access these habitats via connected pathways. Determining where barriers to connectivity exist and their influence on population characteristics and dynamics may allow policymakers and managers to develop meaningful conservation and management actions.

Understanding the potential for fish to move across both geopolitical boundaries and physical barriers is critical to understanding the factors that influence river fish population dynamics. The Red River of the North (hereafter Red River) is formed in North Dakota and Minnesota, USA, and flows north into Manitoba, Canada, before entering into Lake Winnipeg. The Red River has a long history as a productive fishery for trophy Channel Catfish *Ictalurus punctatus*. This system poses challenges in that fish are free to move

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between the USA and Canada (Macdonald, 1990; Hegrenes, 1992; Murray and MacDonnell, 2009), where harvest regulations are different and between the Red River and Lake Winnipeg (Macdonald, 1990) where commercial fishing may influence survival of Channel Catfish. Furthermore, potential barriers to movement exist that may influence population dynamics across the system. We therefore examined this novel fishery in an attempt to understand how a species capable of moving extensive distances is influenced by varying harvest regulations and exposure to potential barriers. We used multistate modelling to determine population parameters (i.e. movement patterns, survival and capture probabilities) of Channel Catfish in the Red River watershed. Specifically, analyses were targeted towards assessing movement probabilities through a suspected point of lost connectivity among upstream and downstream habitats (i.e. St. Andrews Dam), as well as probabilities of movement to areas under differing management strategies.

METHODS

Study area

The Red River is formed at the confluence of the Bois de Sioux and Otter Tail rivers along the Minnesota–North Dakota border and is part of the Hudson Bay drainage of Canada. The Red River flows north for 873 km, ultimately emptying into Lake Winnipeg (Koel and Peterka, 2003). The river forms the border between Minnesota and North Dakota in the USA for 640 km, and the final 233 km is in southern Manitoba. The Red River drainage basin within the USA encompasses parts of western Minnesota, eastern North Dakota and a small portion of northeastern South Dakota, draining a total of 108 800 km^2. The Red River drains an area of 185 474 km^2 in Canada, most of which is in the Assiniboine watershed.

Sampling locations

The focus of this sampling effort was divided among four reaches (Figure 1): (i) a 5-km reach near the mouth of the Red River at Lake Winnipeg (hereafter, Netley Marsh; sampled 2012–2015); (ii) a 15-km reach between the St. Andrews Dam downstream to the town of Selkirk, Manitoba (hereafter, Selkirk; sampled 2012–2015); (iii) a 5-km reach on the north side of the city of Winnipeg (hereafter, Winnipeg; sampled 2014); and (iv) a 5-km reach at the Canada–USA international border (hereafter, Emerson; sampled 2014–2015). These sampling locations allowed sampling of the Channel Catfish population in selected reaches along the length of the Red River in Manitoba and focus on key areas such as the mouth of the river and the international border to capture movement. We considered observed movements of Channel Catfish less than 15 river kilometers (rkm) as localized movements, because our largest sampling reach (Selkirk) was 15 rkm long.

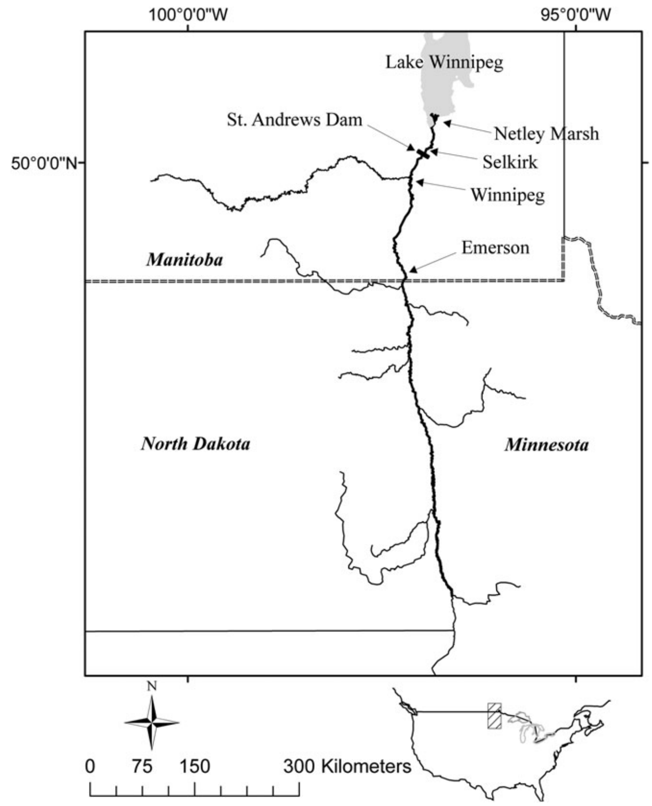

Figure 1. Map of the Red River of the North watershed. Sample reach locations are indicated by name and arrow

Data collection

Channel Catfish were collected from the Red River using hoop nets and rod-and-reel angling during 2012–2015. Hoop nets had seven, 0.9-m diameter hoops and were baited with soy bean mash. Terminal tackle was primarily 6/0 barbless circle hooks baited with cut Goldeye (*Hiodon alosoides*) and White Sucker (*Catostomus commersonii*). Channel Catfish were weighed to the nearest gram, measured for maximum total length to the nearest millimeter and tagged with a T-bar anchor tag inserted through the pterigiophores on the left side (Guy *et al.,* 1996). Channel Catfish that were 200–500 mm received a smaller tag (Floy mfg, 68-B), and Channel Catfish greater than 500 mm received a larger tag (Floy mfg., 67-F). Channel Catfish less than 200 mm were not tagged because smaller catfish are not targeted by anglers, and the tag would be too large relative to the body size and may influence survival and behaviour. Each tag was labelled with a toll-free phone number for anglers to report caught fish and a unique serial number to

DOI: 10.1002/rra

identify individual fish. Channel Catfish were also collected using experimental gill nets on Lake Winnipeg by Manitoba Conservation and Water Stewardship staff during June 2013 and 2014. Channel Catfish were not specifically targeted in Lake Winnipeg but were caught as by-catch while conducting annual Walleye *Sander vitreus* census sampling. Tagging efforts on Lake Winnipeg were located at 10 sites throughout the south basin of the lake (Manitoba Conservation and Water Stewardship, unpublished data).

Movement analysis

We used multistate models (a modification of the Cormack–Jolly–Seber model, multistate recaptures only model; White and Burnham, 1999) to estimate movement rates of Channel Catfish in the Red River with Program MARK. Multistate models use maximum likelihood estimation procedures to estimate survival (S), movement (Ψ) and capture probability (p) parameters. Angler recaptures for all objectives were grouped into the state where fish were recaptured and the sampling period closest to the recapture date. We estimated movement rates between states for all catfish >200 mm and also for an 'angler-susceptible' size group of catfish ≥668 mm. The angler-susceptible size group was used to represent fish commonly captured by anglers within this fishery, as 95% of the Channel Catfish that were angled from the Selkirk reach were at least 668 mm (Siddons *et al.,* 2016). A total of 14 monthly periods were used to cover sampling events as equally as possible and used for movement analyses (Table I). The monthly periods represent months that catfish are susceptible to being sampled and caught by anglers (i.e. April–October annually). We accounted for disparities in time between fall and spring encounter occasions by designating unequal intervals between periods in the models. We used Akaike's information criterion for small sample sizes to select the best model by choosing the model with the lowest Akaike's information criterion score. Model weights were used to assess the strength of the top model, relative to the other models.

St. Andrews Dam passage

The first objective was to estimate movement rates through St. Andrews Lock and Dam. All fish tagged or recaptured above the dam were pooled into an 'A' (Above) state, and all fish tagged or recaptured below the dam were pooled into a 'B' (Below) state. If a fish was not encountered in a given period, it was assigned a zero. We tested two hypotheses regarding survival by including models where the survival parameter was set to constant among periods and groups ($S_{AB\cdot}$) and where survival was set to constant among periods but different between groups ($S_{A\cdot}$ and $S_{B\cdot}$; Table II). We assumed survival would be constant over the length of this study because of the longevity displayed by Red River

Table I. Monthly periods used for movement analyses in Program MARK

Year	Period	Months
2012	1	August
	2	September
2013	*3*	May–June
	4	July
	5	August
	6	September–October
2014	*7*	May–June
	8	July
	9	August
	10	September–October
2015	*11*	May–June
	12	July
	13	August
	14	September–October

Channel Catfish (Siddons *et al.,* 2016) but may be different above and below the dam. Movement from above the dam to below the dam was fixed to zero, as no downstream movements through the dam were observed. We hypothesized that movement rates may vary throughout the year, so upstream movement through the dam was analysed as both a function of time (Ψ_{BAt}) and as a constant ($\Psi_{BA.}$). We also hypothesized that capture probabilities would be greater below the St. Andrews Lock and Dam because of anecdotal observations of greater densities of angler-susceptible sized Channel Catfish and greater angling pressure and that capture probabilities could vary throughout the year. Therefore, we tested models with capture probabilities as a function of time and as a constant but varied among groups (p_{At}, p_{Bt}, $p_{A.}$, $p_{B.}$). The first three periods were constrained to zero for Ψ_{BA} and p_A, as no fish were observed above the dam during those periods.

Manitoba–USA movement

The second objective was to estimate movement rates of Channel Catfish to or from Manitoba (state 'M') and the USA (state 'U'). The same movement parameters (i.e. constant versus time variation by group) were analysed because we hypothesized that movement rates may vary throughout the year (Table III). We included models with survival parameters set as a constant through time among groups and constant through time but different between groups. We did not expect survival to vary over our monthly periods, given the longevity seen in this population of Channel Catfish, but it may be different between states. We chose to hold capture probability as a constant through time with differences between groups in this model because there was little difference in capture probability estimates for the St. Andrew's Dam passage model, and all recaptures in the USA

Table II. Suite of models used to estimate parameters for St. Andrews Dam passage by angler-susceptible Channel Catfish (≥668 mm) in the Red River of the North during 2012–2015

Models	Parameters	Delta AICc	Weight
$S_{AB.}\Psi_{AB=0}\Psi_{BA1-3=0,4-14.}\ p_{Bt}p_{A1-3=0,4-14t}$	30	0	0.71
$S_{A.}S_{B.}\Psi_{AB=0}\Psi_{BA1-3=0,4-14.}\ p_{Bt}p_{A1-3=0,4-14t}$	31	1.8	0.29
$S_{AB.}\ \Psi_{AB=0}\Psi_{BA1-3=0,4-14t}\ p_{Bt}p_{A1-3=0,4-14t}$	41	10	0
$S_{A.}S_{B.}\Psi_{AB=0}\Psi_{BA1-3=0,4-14t}\ p_{Bt}p_{A1-3=0,4-14t}$	42	12	0
$S_{AB.}\ \Psi_{AB=0}\Psi_{BA1-3=0,4-14t}\ p_{Bt}p_{A1-3=0,4-14.}$	30	26	0
$S_{A.}S_{B.}\Psi_{AB=0}\Psi_{BA1-3=0,4-14t}\ p_{Bt}p_{A1-3=0,4-14.}$	31	28	0
$S_{AB.}\Psi_{AB=0}\Psi_{BA1-3=0,4-14.}\ p_{Bt}p_{A1-3=0,4-14.}$	*19*	31	0
$S_{A.}S_{B.}\Psi_{AB=0}\Psi_{BA1-3=0,4-14.}\ p_{Bt}p_{A1-3=0,4-14.}$	21	32	0
$S_{A.}S_{B.}\Psi_{AB=0}\Psi_{BA1-3=0,4-14.}\ p_{B.}p_{A1-3=0,4-14t}$	19	53	0
$S_{AB.}\ \Psi_{AB=0}\Psi_{BA1-3=0,4-14.}\ p_{B.}p_{A1-3=0,4-14t}$	18	55	0
$S_{AB.}\ \Psi_{AB=0}\Psi_{BA1-3=0,4-14t}\ p_{B.}p_{A1-3=0,4-14t}$	29	58	0
$S_{A.}S_{B.}\Psi_{AB=0}\Psi_{BA1-3=0,4-14.}\ p_{B.}p_{A1-3=0,4-14t}$	8	84	0
$S_{AB.}\ \Psi_{AB=0}\Psi_{BA1-3=0,4-14.}\ p_{B.}p_{A1-3=0,4-14.}$	7	84	0
$S_{A.}S_{B.}\Psi_{AB=0}\Psi_{BA1-3=0,4-14t}\ p_{B.}p_{A1-3=0,4-14.}$	19	86	0
$S_{AB.}\ \Psi_{AB=0}\Psi_{BA1-3=0,4-14t}\ p_{B.}p_{A1-3=0,4-14.}$	18	87	0
$S_{A.}S_{B.}\Psi_{AB=0}\Psi_{BA1-3=0,4-14t}\ p_{B.}p_{A1-3=0,4-14t}$	30	87	0

AICc, Akaike's information criterion.

were from recreational anglers. No Channel Catfish were tagged in the USA; therefore, we fixed capture and movement parameters to zero until Channel Catfish were known to move into that state (i.e. recaptured there). Only one Channel Catfish was documented moving from the USA to Manitoba. However, the movement parameter from the USA to Manitoba was still constrained to zero because one data point did not fully inform the model.

Lake Winnipeg connectivity

The final objective was to estimate movement rates of Channel Catfish between Lake Winnipeg (state 'L') and the lower Red River ('R'). Only data from the reaches below St. Andrews Dam (Netley Marsh and Selkirk) were used because no downstream movement from above St. Andrews Dam was observed. We tested two survival hypotheses; first, as a constant through time and equal between the lake and the river ($S_{RL.}$), and second, as a constant through time but different between areas ($S_{R.}$ and $S_{L.}$; Table IV). The movement parameter from Lake Winnipeg to the river was constrained to equal zero, as only one fish was documented moving from the lake to the river. We also tested the hypothesis that movement may depend on the time of year, so the movement parameter from the river to the lake was allowed to vary by time (Ψ_{RLt}) but also modelled as a constant through time ($\Psi_{RL.}$). Capture probabilities were also modelled as both a function of time, and as constant through time, but different for both groups (p_{Rt}, p_{Lt}, $p_{R.}$, $p_{L.}$). We hypothesized that different capture probabilities could occur because recreational angling for Channel Catfish in the river is believed to be greater than the lake. We used 13 monthly periods, rather than 14, because no Channel Catfish in the small size group were recaptured in either location during the final period.

RESULTS

Movement summary

We tagged 13 892 Channel Catfish ($n_{2012} = 461$, $n_{2013} = 3\ 478$, $n_{2014} = 8\ 248$, $n_{2015} = 1\ 705$) and collected 553

Table III. Suite of models used to estimate parameters for Manitoba to USA movement by angler-susceptible Channel Catfish (≥668 mm) in the Red River of the North during 2012–2015

Models	Parameters	Delta AICc	Weight
$S_{M.}S_{U.}\Psi_{UM=0}\Psi_{MU1-3=0,4-14t}\ p_{M.}p_{U1-3=0,4-14.}$	19	0	0.97
$S_{M.}S_{U.}\Psi_{UM=0}\Psi_{MU1-3=0,4-14.}\ p_{M.}p_{U1-3=0,4-14.}$	8	7	0.03
$S_{MU.}\Psi_{UM=0}\Psi_{MU1-3=0,4-14.}\ p_{M.}p_{U1-3=0,4-14.}$	7	11	0
$S_{MU.}\Psi_{UM=0}\Psi_{MU1-3=0,4-14t}\ p_{M.}p_{U1-3=0,4-14.}$	18	13	0

AICc, Akaike's information criterion.

DOI: 10.1002/rra

Table IV. Suite of models used to estimate parameters for movement of Channel Catfish (<668 mm) from the lower Red River of the North (Selkirk and Netley Marsh) to Lake Winnipeg during 2012-2015.

Models	Parameters	Delta AICc	Weight
$S_{\mathrm{RL.}}\Psi_{\mathrm{LR=0}}\Psi_{\mathrm{RL1-2=0,3-13.}}\ p_{\mathrm{R.}}\mathrm{p}_{\mathrm{L1-2=0,3-13}t}$	28	0	0.83
$S_{\mathrm{R.}}S_{\mathrm{L.}}\Psi_{\mathrm{LR=0}}\Psi_{\mathrm{RL1-2=0,3-13t}}\ p_{\mathrm{R}t.}\mathrm{p}_{\mathrm{L1\text{-}2=0,3-13}t}$	39	4	0.1
$S_{\mathrm{RL.}}\Psi_{\mathrm{LR=0}}\Psi_{\mathrm{RL1-2=0,3-13}t}\ p_{\mathrm{R}t}\ \mathrm{p}_{\mathrm{L1-2=0,3-13}t}$	38	5	0.07
$S_{\mathrm{RL.}}\Psi_{\mathrm{LR=0}}\Psi_{\mathrm{RL1-2=0,3-13.}}\ p_{\mathrm{R.}}\ \mathrm{p}_{\mathrm{L1-2=0,3-13.}}$	7	24	0
$S_{\mathrm{R.}}S_{\mathrm{L.}}\Psi_{\mathrm{LR=0}}\Psi_{\mathrm{RL1-2=0,3-13.}}\ p_{\mathrm{R.}}\mathrm{p}_{\mathrm{L1-2=0,3-13.}}$	8	1427	0
$S_{\mathrm{R.}}S_{\mathrm{L.}}\Psi_{\mathrm{LR=0}}\Psi_{\mathrm{RL1-2=0,3-13.}}\ p_{\mathrm{Rt}}\ p_{\mathrm{L1-2=0,3-13t}}$	29	2795	0
$S_{\mathrm{RL.}}\Psi_{\mathrm{LR=0}}\Psi_{\mathrm{RL1-2=0,3-13}t}\ p_{\mathrm{R.}}\ \mathrm{p}_{\mathrm{L1-2=0,3-13.}}$	17	2802	0
$S_{\mathrm{R.}}S_{\mathrm{L.}}\Psi_{\mathrm{LR=0}}\Psi_{\mathrm{RL1-2=0,3-13t}}\ p_{\mathrm{R.}}\mathrm{p}_{\mathrm{L1-2=0,3-13.}}$	18	2804	0

AICc, Akaike's information criterion.

recaptures. A number of these fish were captured multiple times, including 28 Channel Catfish, which were recaptured twice and three that were recaptured three times. Catfish tagged in Manitoba were recaptured as far away as tributaries in the upper watershed (e.g. Red Lake River, Minnesota, and Sheyenne River, North Dakota; Figure 1). The greatest distance observed was 703 km, from Selkirk, Manitoba, to the Sheyenne River, near Harwood, North Dakota. The mean time at large was 279 days (median = 315 days; range: 0–1122 days, Figure 2). We documented a distinct trend where large Channel Catfish (>600 mm) moved greater distances than smaller individuals (Figure 3). Upstream movements were often (55%) through the St. Andrews Dam, but only large fish (>600 mm) passed the dam, and no downstream movement through the St. Andrews Dam occurred. Additionally, 19% of recaptures were reported from the USA. Localized recaptures ($n = 356$; <15 rkm movement) were more common than long distance movements ($n = 197$; >15 rkm movement). Excluding fish tagged and recaptured in Lake Winnipeg, upstream movements ($n = 137$; upstream movements >15 rkm) were more common than downstream movements ($n = 27$; downstream movements >15 rkm). Mean distance travelled was 95 rkm (median = 7.9 rkm; range: 0–703 rkm). Mean distance moved of angler susceptible Channel Catfish (≥668 mm) was 116 km (median = 8.6 rkm; range: 0–703 rkm), and

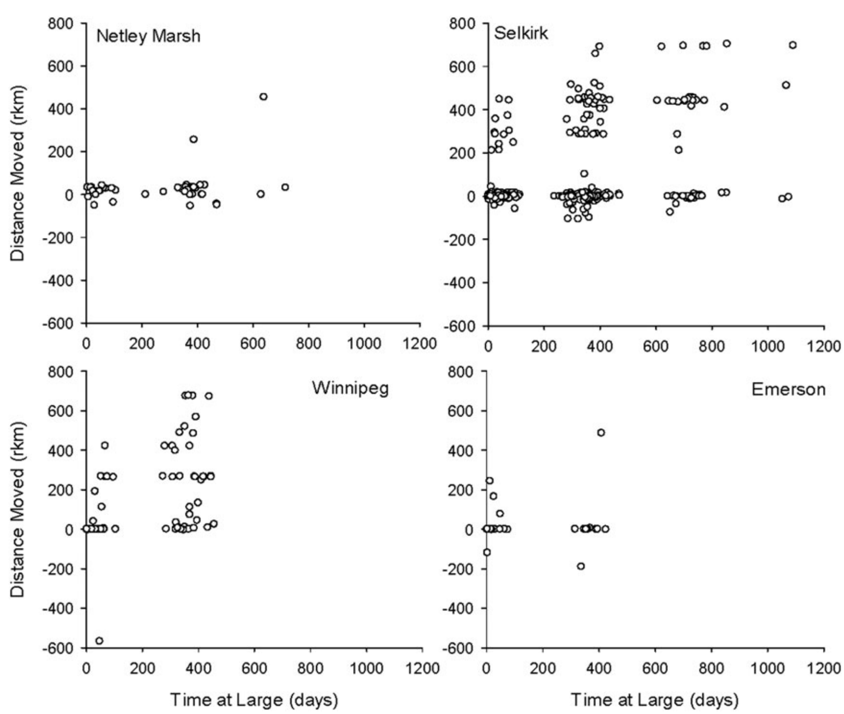

Figure 2. Observed distances moved (river kilometer) and time at large (days) by recaptured Channel Catfish in the Red River of the North during 2012–2015. Positive distances are upstream movements, and negative values are downstream movements from initial tagging location. Upstream movements >200 rkm from Netley Marsh and Selkirk are through St. Andrews Dam

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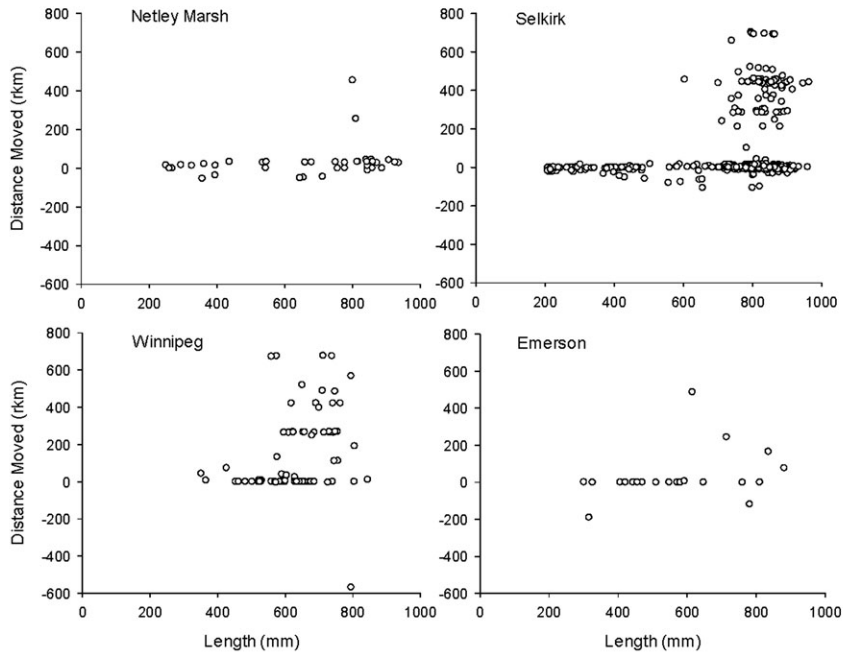

Figure 3. Observed distances moved (river kilometer) and length at tagging (millimeter) by recaptured Channel Catfish in the Red River of the North during 2012–2015. Positive distances are upstream movements, and negative distances are downstream movements from initial tagging location. Upstream movements >200 rkm from Netley Marsh and Selkirk are through St. Andrews Dam

mean distance moved by small (<668 mm) Channel Catfish was 47 rkm (median = 5.8 rkm; range: 0–675 rkm).

St. Andrews Dam passage

Only the angler-susceptible size group was used because only one catfish less than 668 mm passed through the dam. The model with the most support for angler-susceptible catfish movement through St. Andrews Dam estimated a constant monthly probability of movement at 9.4% (95% CI: 6.1–14.2%; model weight = 71%; Table II). The monthly survival estimate was constant through time and equal above and below the dam (95% survival; CI: 94–97%). Capture probabilities varied by time but were similar above and below the dam with a mean of 2% (estimate range: 0.4–5.7%).

Manitoba–USA movement

Only the angler-susceptible size group was used for this analysis because few Channel Catfish less than 668 mm moved to the USA ($n = 12$). The model with the most support for angler-susceptible catfish movement between Manitoba and the USA estimated monthly movement rates that varied by time, with a range of estimates from 0 to 21.9% (mean = 5.6%; model weight = 97%; Table III). Survival estimates were constant but different between the USA (82.9% monthly; (95% CI = 68–91.7%) and Manitoba (97.5% monthly; 95% CI = 95.9–98.5%). Capture probabilities were constant and greater in the USA (3.7% monthly; 95% CI = 1.8–7.3%) than in Manitoba (1.3% monthly; 95% CI = 1.1–1.5%).

Lake Winnipeg connectivity

Few large fish were tagged and recaptured in the lake ($n = 6$ tagged, $n = 3$ recaptured); therefore, only the small size grouping (200–667 mm) was used. The model with the most support estimated a constant movement rate from the lower river (Selkirk and Netley Marsh combined) to Lake Winnipeg at a monthly rate of 2.2% (95% CI: 0.5–8.8%; model weight = 83%; Table IV). Monthly capture probabilities were similar between both areas with most estimates below 1%. Monthly survival estimates were constant and equal between the lower river and the lake at 98.8% (95% CI: 78.0–100%).

DISCUSSION

We documented movements of Channel Catfish throughout the Red River watershed. The most common trend was large Channel Catfish (>600 mm) moving upstream through St. Andrews Dam to the USA where catfish management goals differ from Manitoba. While previous studies on Channel Catfish in the Red River were limited in their ability to document movement trends, they still observed basin-wide movements (Macdonald, 1990; Hegrenes, 1992; Robert, 1992, Murray and MacDonnell 2009). It appears that

DOI: 10.1002/rra

Channel Catfish in the Red River are completing regular basin-wide movements, highlighting the importance of maintaining habitat connectivity throughout a watershed.

St. Andrews Dam is likely functioning as at least a partial barrier to fish movement within the Red River. Our results suggest that large individuals are capable of navigating upstream through the dam with some regularity, but disparities in returns may mean that catfish are not attempting to move through the dam annually or are failing to pass the dam in some years. Previous studies documented downstream movements through the dam, but none were observed during our study. Small individuals are likely not capable of passing upstream through St. Andrews Dam as they were not observed passing the dam but moved between other states. While it appears the dam is semi-permeable (unidirectional), there are likely ecological implications for limited connectivity due to physical habitat fragmentation. In this system, catfish from the lower river in Manitoba may be supporting, either in part or total, the population. Pracheil *et al.* (2014) found Paddlefish *Polyodon spathula* from an upstream reservoir were substantially supplementing downstream populations through downstream dam passage. We were unable to determine the timing of movements because sampling was restricted to the open-water season when they are susceptible to angling. Channel Catfish are seldom considered a true migratory species despite observations of regular, long distance movements (Newcomb, 1989; Pellett *et al.,* 1998; Butler and Wahl, 2011). It is possible that only a proportion of the population is inclined to migrate, which has been documented for other fish species (Gillanders *et al.,* 2015), but the impetus for migration in the Red River is still unclear and is influenced by the presence of St. Andrews Dam.

Geopolitical boundaries within a watershed, such as the Red River, can create disparities in management of a fishery. Stakeholders may not have management and conservation priorities that are in line with each other, which the fishery may or may not be able to withstand. This was evident within the Red River fishery, as survival estimates were lower in the USA. Reduced survival in the USA was corroborated within our tag returns where 21% of recaptured Channel Catfish were harvested in the USA, compared with only 6% in Manitoba (the majority of which were killed as by-catch within the Lake Winnipeg commercial fishery). More liberal harvest regulations appear to be reducing the survival of Channel Catfish in the USA portion of the Red River, and anecdotal evidence suggests additional fishing mortality is present within Lake Winnipeg because of mortality as by-catch from commercial Walleye harvest. While conservative regulations in Manitoba appear to be sustaining the trophy fishery (Siddons *et al.,* 2016), increased harvest in Lake Winnipeg from the commercial fishery or in the USA from more liberal regulations could alter population dynamics of the trophy fishery within Manitoba.

Connectivity is a fundamental property of rivers, which poses challenges for science and management (Moore 2015), as fragmentation of rivers and riverine fish populations can occur because of both physical and political forces. While the negative effects of physical fragmentation are well known and documented (e.g. Alo and Turner, 2005; Liermann *et al.,* 2012; Pracheil *et al.,* 2014; Perkin *et al.,* 2015), the effects of fragmentation due to geopolitical boundaries are more difficult to identify and quantify. Treating a single population as a set of independent units for management purposes may alter population dynamics throughout the entire population, which further complicates management and conservation of large river fish species. Riverine processes, and the fish adapted to them, operate within a well-defined ecological boundary. Recent evaluations of large rivers and their biota have called for adapting management methods that account for the breadth of ecological boundaries (i.e. watersheds; Pracheil et al. 2012, Koehn, 2015, Moore 2015, Pope *et al.,* 2016). However, this study highlights the inconsistency between the scales at which fisheries management is currently conducted and the scale of river systems because ecological boundaries rarely align with human-defined jurisdictions. Management zones that fail to encompass the breadth of the ecological range of a given population are likely ineffective for all parties unless they are working towards shared goals. While river beds, jurisdictional borders and dams are difficult to move, fisheries scientists are not, and cooperative management at a watershed level should be an integral component of fisheries management and conservation in the future.

ACKNOWLEDGEMENTS

Financial support for this project was provided by the Fisheries and Wildlife Enhancement Fund of Manitoba, Manitoba Conservation and Water Stewardship and the University of Nebrask–Lincoln.

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