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Trapping mortality accelerates the decline of the fisher, an endangered mesocarnivore, in British Columbia, Canada

Rory D. Fogarty[1,2,*], Richard D. Weir[2], Eric C. Lofroth[3], Karl W. Larsen[4]

[1]Environmental Science Program, Thompson Rivers University, Kamloops, BC V2C 0C8, Canada
[2]Ministry of Environment and Climate Change Strategy, Government of British Columbia, Victoria, BC V8W 9M1, Canada
[3]Boreas Ecological, Victoria, BC V9E 2B1, Canada
[4]Department of Natural Resource Sciences, Thompson Rivers University, Kamloops, BC V2C 0C8, Canada

ABSTRACT: Understanding the environmental, demographic, and anthropogenic factors driving the population dynamics of endangered species is critical to effective conservation. Habitat loss, fragmentation, and trapping all have been linked to declines in the endangered population of fishers *Pekania pennanti* in central British Columbia (BC), Canada, hereafter referred to as the Columbian population. Although the commercial trapping season for fishers has recently been closed in central BC, the animals are still taken in traps legally set for other furbearer species, and with this continuing source of mortality, the sustainability of this vulnerable population remains unclear. We constructed population viability models in the program Vortex to evaluate the specific impacts that trapping mortality would have on Columbian fisher population persistence under different trapping scenarios. Our modeling predicted that current mortality sources, including deaths in traps set for other species, will cause the population to disappear within 11 yr. When fur harvest mortality was removed from our modeling, the Columbian population appeared unlikely to persist beyond 37 yr. Our analysis provides evidence that along with the continued trapping closure for fishers in central BC, it is likely necessary to modify trapping regulations and methods (including restricting the use of kill traps) for other furbearers within Columbian fisher range to sufficiently reduce mortality from bycatch and help to avoid extirpation of the population in the near future. Additionally, identifying areas where fishers are actively breeding and protecting these habitats from further disturbances will be needed to increase survival and reproductive rates to levels high enough to reverse population declines over the longer term.

KEY WORDS: Fisher · *Pekania pennanti* · Trapping mortality · Population modeling · Extirpation · British Columbia · Mesocarnivore · Mustelid

1. INTRODUCTION

Carnivores of all sizes play influential roles in regulating ecosystems through trophic interactions limiting prey abundance, the subsequent effects on vegetation dynamics, and intraguild competition between larger and smaller predators (Prugh et al. 2009, Ritchie et al. 2012). However, mammalian carnivores worldwide face a multitude of threats including habitat loss and fragmentation, predator control programs, and unsustainable levels of hunting and trapping (Prugh et al. 2009, Wolf & Ripple 2017). In North America, several carnivore species have contracted their ranges over the past 2 centuries following Euro-American colonization of the continent and the ensuing development and demand for resources neces-

*Corresponding author: Fogarty.rory@gmail.com

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sary to support an expanding human population (Laliberte & Ripple 2004). Although some species have re-established in portions of their historical ranges, many have not, and continue to decline in abundance (Gittleman et al. 2001, Wolf & Ripple 2017). Understanding the key environmental, demographic, and anthropogenic factors driving the dynamics of endangered carnivore populations is crucial to ensuring the persistence of these important species over time (Yackulic et al. 2011, Wolf & Ripple 2017).

Fishers *Pekania pennanti* are medium-sized members of the family Mustelidae that inhabit boreal and temperate forests of North America (Powell 1993). Like many other carnivores, the species has experienced significant range contractions since the late 1800s (Laliberte & Ripple 2004, Lofroth et al. 2010). Following European settlement, fisher range contracted northward primarily due to habitat loss resulting from commercial timber harvest and agricultural land clearing, and overexploitation in the fur trade (Lofroth et al. 2010, Lewis et al. 2012, LaPoint et al. 2015). By the early 1900s, large-scale habitat loss, coupled with high pelt prices and minimal fur harvest regulations, led to the decimation of many fisher populations across the southern extent of their range (Lewis et al. 2012). Subsequent protective measures, translocation efforts, and the reversion of agricultural lands back to forest have enabled fishers to recolonize some of their historical range in eastern North America. West of the Rocky Mountains, however, fishers continue to exist as smaller and more isolated populations in British Columbia (BC), Canada, and in a handful of western states in the USA (Lofroth et al. 2010).

As elsewhere within their range, fishers in BC are habitat specialists, with survival and reproduction contingent on unique structural elements typically found in late-successional forests (Raley et al. 2012, Weir et al. 2012). Structures used for denning and resting are essential habitat features primarily associated with deformed and decaying live trees and include cavities, platforms, and other microstructures (Weir & Harestad 2003, Aubry & Raley 2006, Purcell et al. 2009). Because these structures are rare and can take up to a century to develop, fishers are highly susceptible to habitat alterations that remove these structures at rates faster than forests can redevelop them (Weir et al. 2012). Over the past 3 decades, the low-elevation forests of central BC have undergone widespread habitat change through ongoing forest harvest, large-scale insect infestations, unprecedented wildfire seasons, and the accelerated rates of salvage logging that followed these disturbances (Eng et al. 2005, Province of British Columbia 2017, 2018).

Fisher densities in BC are some of the lowest documented from anywhere within their range (e.g. 8.8 fishers per 1000 km^2; Weir & Corbould 2006), prompting concerns among wildlife managers, stakeholders, First Nations, and conservation groups over the decline of these animals and their habitat. Moreover, recent research indicates that there are 2 distinct fisher populations in BC (hereafter named the Boreal population and Columbian population, respectively) separated by a high snowpack zone encompassing the Rocky Mountain divide and the mountainous region south of the Spatsizi Plateau (Fig. 1; BC CDC 2020). Given that fishers have already been extirpated from most of southern BC, this work suggests that the Columbian fisher population has effectively been isolated from any other population on the continent.

As a result of patterns in habitat loss and the accompanying decline in population size, the status of the Columbian fisher population was revised to endangered by the BC government (Province of British Columbia 2020). This was accompanied by the cessation of commercial fisher trapping within the range of the Columbian fisher population (Province of British Columbia 2021). However, fishers continue to be

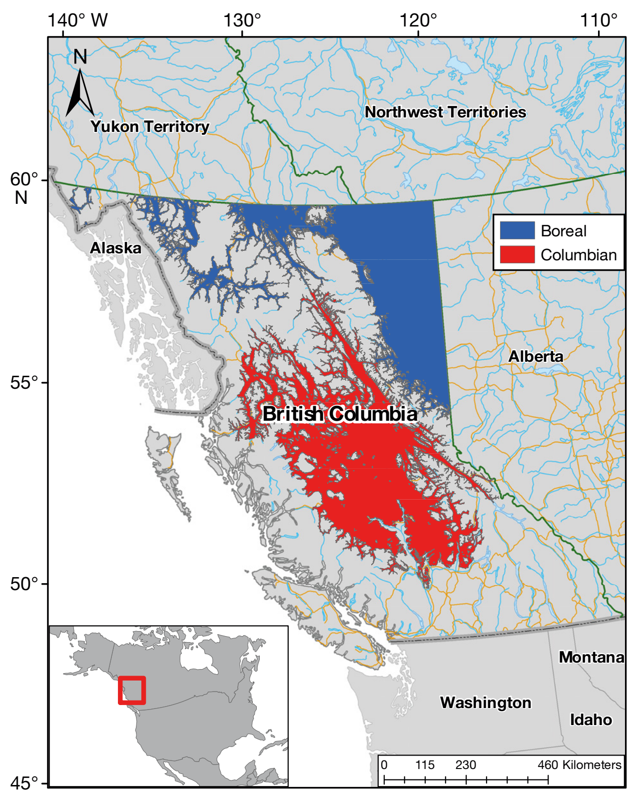

Fig. 1. Current range of the 2 fisher *Pekania pennanti* populations (Boreal and Columbian) in British Columbia, Canada (BC CDC 2020)

taken as bycatch in traps designed and set for other furbearing species (e.g. traps designed for American marten *Martes americana* account for 52% of annual fisher mortality; Province of British Columbia unpubl. data: Compulsory Reporting 2013–2018 [accessed 15 July 2021]). Therefore, the objective of our study was to specifically evaluate the effects that this mortality from trapping bycatch may be having on the sustainability of the Columbian fisher population. We used field-collected data on fisher reproduction and survival from central BC along with data from the provincial fur harvest database in population viability models to project the population response to different levels of trapping mortality. We predicted that low reproductive output and high rates of natural female mortality in Columbian fishers would affect the ability of this population to endure additional, additive mortality from trapping. The knowledge gained from this study will allow us to craft more effective population management measures to help ensure that this population persists over the long term.

2. MATERIALS AND METHODS

2.1. Study area

The range of fishers within the Columbian population encompasses forested habitats at low to moderate elevations in central BC (Fig. 1; Weir 2003). Northern and central portions of this range consist of the Sub-Boreal Spruce biogeoclimatic zone (Meidinger et al. 1991), whereas the southerly portion of the range primarily consists of drier ecological zones including the Sub-Boreal Pine–Spruce (Steen & Demarchi 1991), Montane Spruce (Hope et al. 1991a), and Interior Douglas-fir (Hope et al. 1991b) biogeoclimatic zones.

2.2. Population viability analysis software

We built population models using Vortex version 10.5.5.0 (Lacy & Pollak 2020), a software program shown to be suitable for populations with low reproductive rates (Lacy 1993, Kim et al. 2016, Winton et al. 2020). Vortex is an individual-based modeling process that simulates population outcomes by sequentially stepping through a series of events describing the annual cycle of a typical sexually reproducing organism (Lacy et al. 2020). It incorporates demographic, environmental, and genetic stochasticity as it follows the fate of individuals from birth to death based on probabilities and user-defined parameters (Lacy et al. 2020). Model outputs include probability of extinction, mean stochastic population growth rate (r), and mean time to extinction.

2.3. Input parameters

We parameterized the initial population model primarily using the survival and reproduction information from Lofroth et al. (in press), who analyzed radio-telemetry and other data from the studies of 60 free-ranging fishers in central BC by Weir (1995), Weir & Corbould (2008), and Davis (2009), along with published literature from a well-studied fisher population in California, USA (Table 1; Sweitzer et al. 2015). We ran 1000 simulations of each model to predict population outcomes over a period of 100 yr using a 1 yr time step and did not include density dependence, catastrophes, inbreeding, or dispersal effects. We set the quasi-extinction threshold as the point when only 1 sex remained and considered this to be the point at which the extirpation of Columbian fishers occurred in the Vortex programming language; hereafter, 'extinction' refers to reaching this threshold. We did not assign any correlation between reproduction and survival due to a lack of empirical data needed to inform this relationship. The current estimate for the Columbian fisher population is 299–517 adult individuals (adult fishers are those animals >2 yr old; BC CDC 2020). Therefore, we used an initial population size scaled upwards from the midpoint of this adult population estimate to include animals in all age cohorts for each simulation (i.e. initial population size of 571 individuals). We used a proportional age distribution for the initial population based upon the most recent data available from central interior BC (Weir & Corbould 2008). We modeled 3 different age cohorts for each sex: adults (>2 yr old), subadults (1–2 yr old), and kits (0–1 yr old).

Vortex defines mortality rates in the language of matrix life-table analysis as the percentage of animals alive at age x that die before reaching age $x + 1$ (Lacy et al. 2020). Survival and subsequent mortality rates were calculated following methods detailed by Lofroth et al. (in press) using monitoring data collected from 3 radio-telemetry studies from central BC. Because these survival calculations included mortalities from trapping, we reran their analyses, excluding fishers that died in traps, using the 'survival' package in the R programming language (R Version 4.0.2; R Core Team 2020). This ensured that only non-trapping sources of mortality were included in the

Table 1. Input parameters and associated data sources for population viability analysis of the Columbian population of fishers *Pekania pennanti* in British Columbia (BC), Canada. Most parameters were derived from 3 radio-telemetry studies on fishers in central BC and 1 small, well-studied population in California. Environmental variation (EV) refers to the annual variation in reproduction and survival due to random changes in the environment and is modeled using the standard deviation for each applicable parameter (Lacy et al. 2020)

Parameter	Value (±EV)	Location	Source
Population parameters			
Initial population size	571	BC	BC CDC (2020)
Carrying capacity	10 000		
Reproductive parameters			
Breeding system	Polygynous	Western North America	Lofroth et al. (2010), Smith et al. (2020)
Age (yr) at first litter (female)	2	BC	Weir (2003), Lofroth et al. (2010)
Age (yr) at sexual maturity (male)	2	BC	Weir (2003), Lofroth et al. (2010)
Maximum age (yr) of breeding	8	Western North America	Lofroth et al. (2010)
Maximum number of progeny per brood	4	Western North America	Lofroth et al. (2010)
Mean number of kits per litter	1.7 (±0.69)	BC	Lofroth et al. (in press)
Sex ratio at birth (in % males)	50	North America	Frost & Krohn (1997), Matthews et al. (2019)
% Females breeding annually	54 (±41)	BC	Lofroth et al. (in press)
% Males breeding annually	100		
Mortality rates (%)			
Kits (age 0–1 yr; female)	43 (±19)	California, USA	Sweitzer et al. (2015)
Kits (age 0–1 yr; male)	43 (±19)	California, USA	Sweitzer et al. (2015)
Subadult (age 1–2 yr; female)	40 (±22)	BC	Lofroth et al. (in press), this study
Subadult (age 1–2 yr; male)	14 (±13)	BC	Lofroth et al. (in press), this study
Adult (age >2 yr; female)	21 (±9)	BC	Lofroth et al. (in press), this study
Adult (age >2 yr; male)	10 (±10)	BC	Lofroth et al. (in press), this study

initial population progression since the effect of annual fur harvest mortality was simulated in Vortex in a separate step. We used kit mortality rates from birth to the age of 1 from an untrapped, well-studied population in California, as it was the most proximate published study that included data on fisher kit survival (Sweitzer et al. 2015).

We used a polygynous breeding system for our models, as both female and male fishers have been documented breeding with multiple partners in the same year (Smith et al. 2020). We set the age at first breeding to be 2 yr old for both males and females. Female fishers can breed at 1 yr of age, but because they exhibit delayed implantation they will not give birth to kits until they are at least 2 yr old (Lofroth et al. 2010). Moreover, although 1 yr old male fishers can produce sperm, it is believed their baculum is not developed enough to cause females to ovulate until they are 2 yr old (Douglas & Strickland 1987, Frost et al. 1997). We used a sex ratio of 50:50 at birth (Frost & Krohn 1997, Matthews et al. 2019). We set the maximum number of litters per year to be 1 and maximum litter size to be 4 kits per litter (Paragi et al. 1994, Aubry & Raley 2006). Not all female fishers successfully breed every year (Powell 1993, Lofroth et al. 2010), and we used the proportion of females breeding annually and average litter size as calculated from the 3 radio-telemetry studies from central BC (Lofroth et al. in press). We assumed that 100% of extant males of reproductive age would be in the breeding pool each year.

We incorporated environmental variation, or the annual variation in reproduction and survival due to random changes in the environment, by incorporating the standard deviation observed from the empirical data with each demographic parameter in our modeling inputs. For each annual iteration, fluctuations in the annual probabilities of mortality and reproduction were modeled as binomial processes based on the mean and standard deviation specified for each parameter (Lacy et al. 2020).

2.4. Model manipulation and sensitivity testing

We initially tested the effect of fur harvest levels on the probability of future extinction using the annual average number of fishers harvested from the Columbian fisher population between 2009 and 2017 (169 fishers, or 29.6% of the initial population; Province of British Columbia unpubl. data: BC Wild Fur Harvest Database [accessed 15 May 2021]). More recent data were unavailable since there was a time lag between harvest reporting and entry in the BC Wild Fur Harvest database. Although the commercial fisher trapping season was recently closed, killing traps certified for trapping other furbearing species also consistently caught a substantial number of fishers every year; therefore, we used provincial fur harvest data to calculate the proportion of fishers caught in different trap types to inform our alternative modeling scenarios (Table 2; Province of British Columbia unpubl. data: Compulsory Reporting 2013–2018 [accessed 15 July 2021]). Both before and after the trapping season closure, most trappers in BC did not specifically set traps to target fishers but typically set traps for the equally valuable and more abundant American marten, as either species could be harvested using the same trap set. As such, 120-class traps (e.g. Belisle SUPER X 120, LDL B120 Magnum), which are primarily used, and certified, for trapping American martens and occasionally American mink *Neovison vison*, accounted for a substantial proportion of fisher harvest during each trapping season (52% of fisher harvest; Province of British Columbia unpubl. data: Compulsory Reporting 2013–2018 [accessed 15 July 2021]). Fishers were also killed in slightly larger traps set specifically for them, but which also captured American martens (e.g. 160- and 220-class traps; 15% of fisher harvest), as well as 280- and 330-class traps set primarily for Canada lynx *Lynx canadensis*, bobcats *L. rufus*, and wolverines *Gulo gulo* (22% of fisher harvest). Leghold traps and snares commonly used for trapping Canada lynx, bobcats, coyotes *Canis latrans*, and grey wolves *C. lupus* accounted for 11% of fisher harvest each year.

Table 2. Proportion of fishers *Pekania pennanti* harvested from the Columbian population in British Columbia, Canada, by trap class as calculated from from the Compulsory Reporting records of fishers trapped each year collected by the provincial government

Trap class	Species typically set for	Overall % of fisher harvest
120[a]	American marten *Martes americana*, fisher[b]	52
160	American marten, fisher	7
220	Fisher, lynx *Lynx canadensis*, bobcat *L. rufus*	8
280	Lynx, bobcat	6
330	Lynx, bobcat, wolverine *Gulo gulo*	16
Foothold	Lynx, bobcat, coyote *Canis latrans*, wolf *Canis lupus*	3
Snare	Lynx, bobcat, coyote, wolf	8

[a]120-class killing traps are currently the only trap type that can be modified to specifically exclude fishers
[b]The commercial fisher trapping season was closed in August of 2021

We simulated the effects of varying levels of trapping mortality on population viability based upon the mortality attributed to these different classes of traps. We considered 4 different scenarios and modeled the effect of mortality under these scenarios on population persistence (Table 3). In Trapping Scenario 1, the harvest of fishers in any trap type continued unabated, which, because fishers are killed in all trap types certified and set for other furbearing species in BC, we expected to remain very similar to the current annual average harvest rate of 169

Table 3. Fur harvest scenarios considered in the projection of population outcomes for fishers *Pekania pennanti* in the Columbian population of British Columbia, Canada. The percentage of the total population removed under each scenario was based upon the annual average reported harvest of fishers between 2009 and 2017 (shown in brackets) and a projected initial population size of 571 fishers. We applied a constant trapping mortality rate using this percentage of the initial population harvested annually to account for the decline in harvest we expected to see each year as the overall population declines (i.e. as the population declines over time, so does the number of fishers harvested). NA: not applicable

Trapping scenario	Trap types that harvest fishers	Typical target species	% of fisher population harvested (n)[a]
0: No fishers harvested in any trap type	NA	NA	0 (0)
1: Fishers harvested in all trap types (status quo)	All trap types	See list below	29.6 (169)
2: Fishers harvested in non-marten sets only	160-, 220-, 280-, 330-class killing, foothold, and snare traps	Fisher, lynx, bobcat, wolverine, coyote, wolf	14.2 (81)
3: Fishers harvested in non-fisher-certified sets only	280-, 330- class killing, foothold, and snare traps	Lynx, bobcat, wolverine, coyote, wolf	9.8 (56)

[a]Based on an initial population size of 571 fishers

fishers per year (29.6% of the initial population). In Trapping Scenario 2, we considered the possibility that mortality from 120-class traps could be eliminated since this is currently the only trap class that can be modified to specifically exclude fishers (I. J. Hansen pers. comm.), but kills from other traps continued. Trapping Scenario 2 simulated the harvest of 81 fishers (14.2% of the initial population) from the population annually and was equal to the annual average number of fishers trapped in non-120-class traps. In Trapping Scenario 3, we considered the possibility that mortality from traps previously certified for use on fishers could be removed from the harvest but kills from other traps continued. Trapping Scenario 3 simulated the harvest of 56 fishers (9.8% of the initial population) which is the annual average number of fishers caught in traps not certified for use on fishers (i.e. 280- and 330-class kill traps, foothold, and snare traps). We assumed the number of fishers harvested each year under these scenarios would decline in concert with overall population declines, therefore we applied a constant trapping mortality rate using the percentage of the initial population harvested annually for each of the 3 trapping scenarios (e.g. 29.6% of the population was harvested annually for Trapping Scenario 1). The percentage of animals harvested from each age–sex class was based on the proportional distribution of carcasses submitted by trappers across BC (Weir 2003). We also considered a No Trapping Scenario (Scenario 0) where no fishers were removed from the population through fur harvest.

We used sensitivity testing to assess the relative influence of each individual input parameter on the predicted model outcomes. We simulated the effects of altering model parameters one at a time while holding all other values constant to better understand the relative sensitivity of each input parameter on the projected stochastic population growth rate. Given the uncertainty associated with the current estimate for the Columbian fisher population, we varied the initial population size in Scenario 0 from 300 to 2000 fishers to evaluate how this factor would change the predicted fate of the population. The age structures of mustelid populations are thought to be inherently unstable (Powell 1994), so we used different starting age distributions from published sources (Weir 1995, Weir & Corbould 2008, Buskirk et al. 2012, Lacy & Pollak 2020) to determine if this would change the projected outcomes. Following similar methodologies used in other studies on fisher demographics in the western USA (Lewis et al. 2012, Sweitzer et al. 2015), we then manipulated additional model parameters by ±10% around initial values to evaluate changes to stochastic population growth rate. These parameters included male and female mortality rates for each age–sex class, litter size, and the proportion of females breeding each year, as well as the associated value of environmental variation for each parameter.

3. RESULTS

3.1. No Trapping Scenario (Scenario 0 — no annual fur harvest mortality)

Scenario 0, which used known rates of natural mortality and reproduction from free-ranging fishers and included no mortality from fur harvest, predicted that the Columbian fisher population in the central interior of BC would become extirpated in 36.9 ± 0.43 yr (mean ± SE), on average (Table 4). The results of this modeling scenario showed a steadily declining Columbian fisher population with a mean population growth rate of −0.1261 ± 0.0015 across all years, and a probability of extinction of 100% in 100 yr.

3.2. Alternative scenarios

We modeled a suite of alternative population scenarios based on status quo annual fur harvest rates to evaluate and predict the probability of extinction for the Columbian fisher population. When fur harvest removed any animals from the population, the probability of extinction was 100% over 100 yr, and extinction was predicted within 21 yr for all 3 scenarios that we considered (Fig. 2, Table 4). Generally, the predicted population growth rate for the Columbian population decreased substantially with increasing levels of fur harvest. Specifically, under the status quo scenario (Scenario 1), which assumed the average annual fur harvest rate of 29.6% of the population continued unabated, the population was predicted to become extinct within 10.7 ± 0.03 yr. Trapping Scenario 2, which assumed that fishers were excluded and not killed in 120-class American marten traps but continued to be caught in all other trap types (48% of annual trapping mortality; Province of British Columbia unpubl. data: Compulsory Reporting 2013–2018 [accessed 15 July 2021]), predicted a population growth rate of −0.2272 ± 0.0023) and a mean time to extinction of 16.5 ± 0.12 yr. Trapping Scenario 3, which assumed that mortality from traps certified for use on fishers could be removed from the

Table 4. Stochastic growth rate, probability of extinction, and mean time to extinction (±SE) for the Columbian population of fishers *Pekania pennanti* in British Columbia (BC), Canada, under different levels of trapping mortality (see Table 3 for scenarios). Simulations were run 1000 times over a period of 100 yr using Vortex software (version 10.5.5.0). Both males and females were available for trapping in these scenarios with an age distribution used from fisher carcass data from BC (Weir 2003). Extinction was considered when only 1 sex remained in the population, and probability of extinction over a period of 100 yr was 100% for all scenarios

Trapping scenario	% of population trapped annually	Rationale	Stochastic population growth rate (r)	Mean time to extinction (yr)
0	0	No fishers trapped in any trap types	−0.1261 ± 0.0015	36.9 ± 0.43
1	29.6	Average number of fishers trapped annually between 2009 and 2017	−0.2739 ± 0.0023	10.7 ± 0.03
2	14.2	Average number of fishers trapped annually between 2009 and 2017 in non-120-class traps[a]	−0.2272 ± 0.0023	16.5 ± 0.12
3	9.8	Average number of fishers trapped annually between 2009 and 2017 in non-fisher-certified traps	−0.2050 ± 0.0021	20.6 ± 0.19

[a]120-class traps typically used for American marten *Martes americana* can be modified to specifically exclude fishers; other trap classes currently cannot

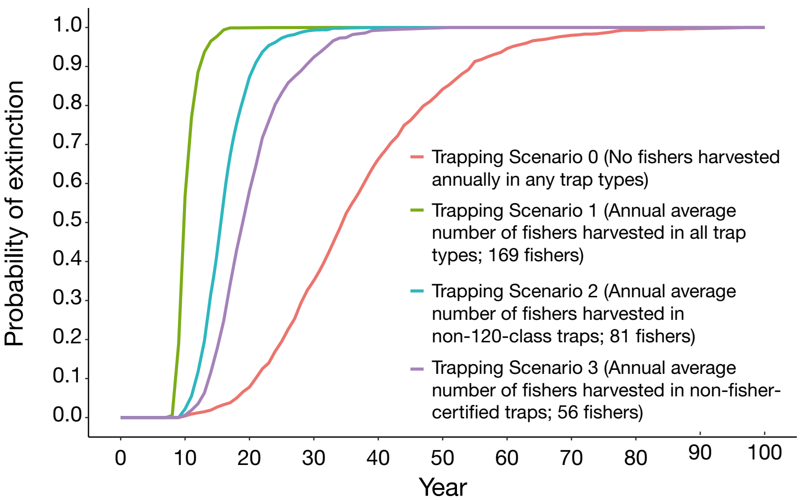

Fig. 2. Influence of alternative levels of mortality from trapping bycatch on the probability of extinction over 100 yr for the Columbian population of fishers *Pekania pennanti* in British Columbia, Canada, using parameterizations listed in Table 1 and trapping scenarios in Table 3. Modeled using Vortex software (version 10.5.5.0)

harvest but kills from other traps continued, predicted a population growth rate of −0.2050 ± 0.0021 and a mean time to extinction of 20.6 ± 0.19 yr.

3.3. Sensitivity testing

We used sensitivity testing to explore the effects that altering other model parameters had on the stochastic population growth rate. Age structures of mustelid populations are thought to be inherently unstable (Powell 1994); however, changing the age distribution used for our initial population had negligible effects on probability of extinction and mean time to extinction, and a moderate effect on the population growth rate (range: −0.1513 to −0.1261; Table 5). Altering the initial population size from 300 to 2000 fishers had very little effect on the predicted population growth rate (range: −0.1336 to −0.1189) or probability of extinction (>99.8% in all scenarios), but it did result in differences in mean time to extinction (range: 34.2–44.3 yr; Table 6). Our population models were most sensitive to adult female mortality, followed by the percentage of females breeding annually, subadult female mortality, and female kit mortality, in order of decreasing significance (Fig. 3). Varying male mortality rates and changing the environmental variation associated with each parameter had little effect on the stochastic population growth rate. Therefore, although there was some uncertainty associated with the values we used for the environmental variation in each demographic rate, refining these values would not change the conclusions drawn about the viability of the population.

To further evaluate the effects that varying female mortality would have on the predicted probability of extinction for the Columbian fisher population, we decreased mortality rates for female fishers in increments of 2% (i.e. mortality rate decreased from 20 to 18%, 18 to 16%, etc.) from the initial values used in Scenario 0, with no additional mortality from trapping

Table 5. Effect of using different age structures on the predicted stochastic population growth rate, probability of extinction, and mean time to extinction (±SE) for the Columbian population of fishers *Pekania pennanti* in British Columbia (BC), Canada, over 100 yr. Extinction was considered when only 1 sex remained in the population, and probability of extinction over a period of 100 yr was 100% for all scenarios. References given in the Source column refer to 'Age distribution' only. Modeled using Vortex software (version 10.5.5.0)

Age distribution	Source	Stochastic population growth rate (r)	Mean time to extinction (yr)
Proportional based on radio telemetry research in BC	Weir & Corbould (2008)	−0.1261 ± 0.0015	36.9 ± 0.43
Proportional based on fisher carcass data from 1988 to 1993 in BC	Weir (1995)	−0.1308 ± 0.0015	36.6 ± 0.40
Proportional based on population model	Buskirk et al. (2012)	−0.1378 ± 0.0015	34.4 ± 0.39
Stable age distribution (as calculated by Vortex 10.5.5.0)	Lacy & Pollak (2020)	−0.1513 ± 0.0016	31.5 ± 0.39

Table 6. Stochastic population growth rate, probability of extinction, and mean time to extinction (±SE) for the Columbian population of fishers *Pekania pennanti* in British Columbia, Canada, over 100 yr with different initial population sizes. Extinction was considered when only 1 sex remained in the population. Modeled using Vortex software (version 10.5.5.0)

Initial population size	Stochastic population growth rate (r)	Probability of extinction (%)	Mean time to extinction (yr)
300	−0.1189 ± 0.0015	100	34.2 ± 0.41
400	−0.1239 ± 0.0014	100	35.3 ± 0.39
571[a]	−0.1261 ± 0.0015	100	36.9 ± 0.43
700	−0.1277 ± 0.0015	99.9	38.4 ± 0.42
1000	−0.1309 ± 0.0014	99.9	40.1 ± 0.43
2000	−0.1336 ± 0.0013	99.8	44.3 ± 0.45

[a]Approximate midpoint of the current estimate for the Columbian fisher population. This was the value used for initial population size in all trapping scenarios

(Fig. 4). Decreasing female mortality rates by 10% resulted in less than half of the 1000 populations simulated going extinct within 100 yr. Decreasing female mortality rates by 12% resulted in a slightly positive stochastic population growth rate and a probability of extinction of less than 25% within 100 yr. When female mortality rates were decreased by 10% and the percentage of females successfully breeding was increased by 10%, the population growth rate became positive at 0.0227 ± 0.0008 (SE) with a probability of extinction <6% within 100 yr.

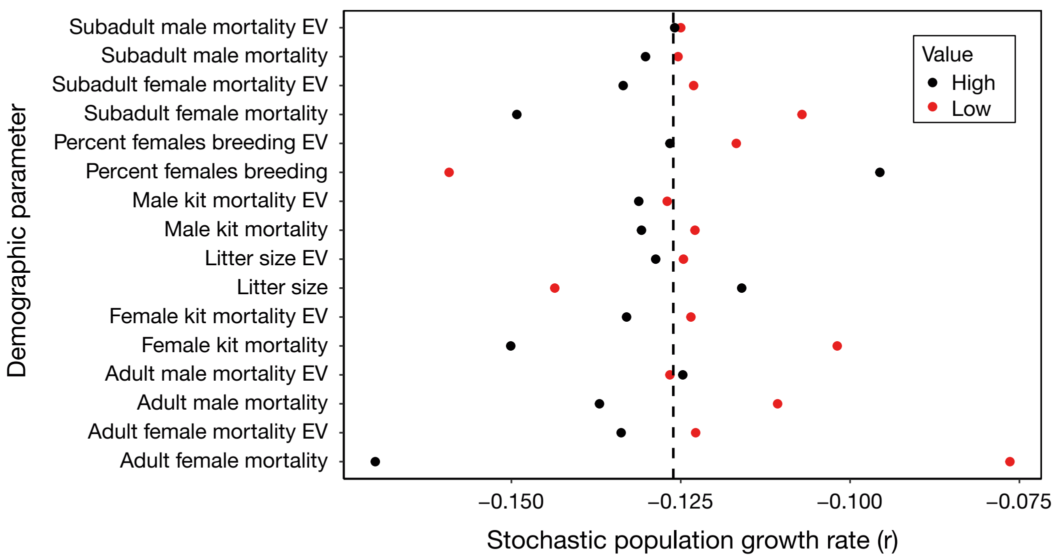

Fig. 3. Effects of varying input parameters for breeding and mortality rates and their associated values of environmental variation (EV) when increased or decreased by ±10% on the stochastic population growth rate for the Columbian population of fishers *Pekania pennanti* in British Columbia, Canada, under Scenario 0 (no trapping mortality). The black dashed line is set at the stochastic population growth rate value for Scenario 0. Red indicates that the parameter value was decreased by 10% and black indicates that the parameter value was increased by 10%. Each parameter was varied while holding all other parameters constant. Modeled using Vortex software (version 10.5.5.0)

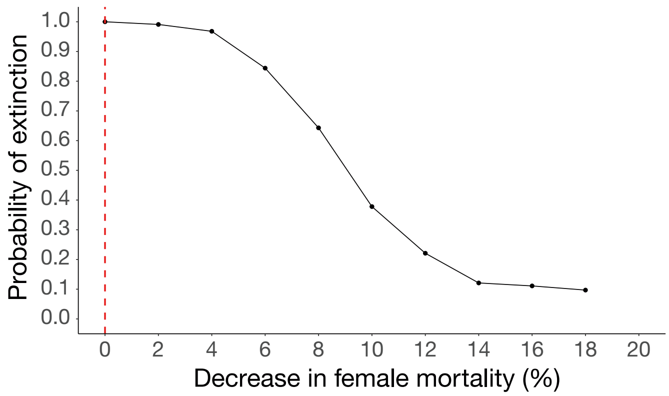

Fig. 4. Effects of decreasing natural female mortality in increments of 2% on the probability of extinction over 100 yr for the Columbian population of fishers *Pekania pennanti* in British Columbia, Canada. The red dashed line at 0 represents natural female mortality rates used for initial population projections, detailed in Table 1, that were derived from 3 radio-telemetry studies on fishers in the central interior of BC between 1995 and 2009. These initial rates were subsequently decreased in increments of 2% to evaluate the effect on probability of extinction, in the absence of any mortality from trapping. Modeled using Vortex software (version 10.5.5.0)

4. DISCUSSION

Our population simulations indicated that, under current reproductive and natural mortality rates, the Columbian fisher population cannot sustain any additional mortality in the form of fur harvest. Because fishers are easily trapped (Powell 1979, 1994), small populations can be put at further risk by the trapping of other furbearers in these same areas (Douglas & Strickland 1987, Powell & Zielinski 1994). The commercial trapping season was discontinued in 2021 within the range of the Columbian population (Province of British Columbia 2021), but fishers in central BC continue to be regularly killed in traps set for other furbearing species which are still legally trapped every year (Province of British Columbia unpubl. data: BC Wild Fur Harvest Database [accessed 15 May 2021]). During the 2 yr that the fisher trapping season was previously closed in BC, the number of fishers incidentally caught exceeded the number legally caught the preceding year (Powell & Zielinski 1994), which suggests that the closure of the fisher trapping season alone will have minimal benefit for this population. Unless trapping regulations are changed in central BC to substantially reduce the number of fishers trapped as bycatch each year, our modeling indicates that the Columbian population will become extirpated from the region in just over a decade.

Closing the commercial trapping season or eliminating the use of body-gripping traps (i.e. killing traps) for other terrestrial furbearers within the Columbian fisher range are likely the most effective ways to eliminate the significant threat that bycatch mortality represents to the persistence of this fisher population. In central BC, most fishers are caught in 120-class killing traps designed for American marten (52%; Province of British Columbia unpubl. data: Compulsory Reporting 2013–2018 [accessed 15 July 2021]). In 2019–2020, the BC Fisher Habitat Working Group initiated a pilot project to design and construct a 'fisher exclusion plate' which can be used to modify 120-class traps to specifically exclude fishers (I. J. Hansen pers. comm.). Legally requiring these 'fisher exclusion plates' to be used by trappers would eliminate most of the risk of fishers being caught in this class of traps and considerably decrease the fisher bycatch in central BC while still allowing some level of marten trapping. However, steadily increasing lumber prices makes the cost of producing these 'exclusion plates' not insignificant and is currently limiting the voluntary adoption of their use by trappers in the province (I. J. Hansen pers. comm.). Trap classes designed for other larger furbearing animals, leghold traps, and snares also account for a substantial proportion of the fisher harvest in central BC (48%; Province of British Columbia unpubl. data: Compulsory Reporting 2013–2018 [accessed 15 July 2021]), and at this time, these other trap classes and types do not have modifications designed to exclude fishers. When we simulated a scenario where only those fishers caught in non-120-class traps were harvested from the population, the mean time to extinction for the Columbian population increased from 10.7 (status quo) to 16.5 yr. These results further demonstrate that without eliminating the bycatch of fishers in traps set for other furbearers through increased trapping regulations, it is highly unlikely that the Columbian fisher population will persist in central BC.

Even when fur harvest mortality was removed from our modeling, projections still indicated a steadily declining Columbian fisher population. While mortality from trapping bycatch may be the proximate threat towards the fisher population in the interior of BC, habitat loss, fragmentation, and degradation are reported to be the primary drivers behind the long-term population declines being seen in the province (Weir 2003, Lofroth et al. 2010, BC CDC 2020). Throughout their range, fishers depend on structures associated with late-successional forests for both survival and reproduction (Lofroth et al. 2010), and reproductive output has been linked to habitat quality (Raley et al. 2012). The dens where fishers birth and raise their kits in BC are exclusively found in the cavities of large-diameter trees (Lofroth et al. 2010, Weir et al. 2012), which are atypical and uncommon in the landscape. Fishers use protected resting sites when not actively hunting or traveling to conserve energy, avoid predation, thermoregulate, and safely consume prey (Lofroth et al. 2010, Raley et al. 2012). In BC, fishers rest in cavities in large-diameter trees, on platforms formed in spruce and subalpine fir trees from abnormal growths caused by spruce broom rust *Chrysomyxa arctostaphyli* or fir broom rust *Melampsorella caryophyllacearum*, and on large branches (Weir 2003, Davis 2009). Forest management has the greatest potential to negatively impact fisher habitat in BC due to the prevalence of clear-cut harvesting with short cutting rotations which removes these important structures at rates faster than they develop under current forest harvesting and secondary successional timelines (Weir & Corbould 2010, BC CDC 2020). Limiting further disturbance to high-value fisher denning and resting habitats in central interior BC will also likely be necessary to promote the recovery of the species in the region.

Our population models were highly sensitive to the loss of reproductive-aged females and the percentage of females successfully producing offspring each year. These results align with other studies from a small, untrapped, and isolated fisher population in the southern Sierra Nevada mountains of California (Lamberson et al. 2000, Sweitzer et al. 2015) as well as published literature on other mammalian carnivores (Hebblewhite et al. 2003, Mills et al. 2018, Hooker et al. 2020), which all found female demographic responses to be important to their study populations. Our simulations were also sensitive to subadult female and female kit mortality, indicative of an overall vulnerability of the population to all forms of female mortality. Furthermore, our modeling results demonstrate that in the absence of any additional mortality from trapping, moderate decreases of 10% in female mortality and increases of 10% in breeding success would have considerably positive impacts on the persistence of the Columbian fisher population. Taken together, the observations that populations are sensitive to female survival and reproductive success and that the loss of fisher denning and resting habitats is likely detrimental to both are concerning, highlighting the troubling reality that without identifying and protecting areas where fishers are actively reproducing it will be challenging to recover the Columbian fisher population to sustainable levels over the longer term.

As with all modeling approaches, there are assumptions and limitations to our predictions. We assumed that reproductive and mortality rates remained constant through time, which may not be the case. We did not include dispersal effects in our models, and our analysis was aspatial and applied to the entirety of Columbian fisher range. Suitable fisher habitat is highly fragmented in BC and there are likely negative effects on the population due to increased dispersal distances for both kits leaving their mothers to establish their own territories, and males and females seeking breeding opportunities. We did not include any effects due to inbreeding depression, which would also likely exert detrimental effects on the population if it continued to decline. Catastrophes such as the large-scale wildfires that are becoming more common were also not included, and we expect the destruction of such extensive areas of the forested habitats that fishers require to have further adverse effects on the population. The potential effects that prey availability may have on fisher populations also went unmodeled. Importantly, it is highly likely that the factors we did not include in our modeling (e.g. dispersal effects) would have additional impacts and would not improve the outlook for this fisher population.

5. CONCLUSIONS

Like many other low-density and wide-ranging carnivores, fishers in the Columbian population in central BC face numerous threats, most notably habitat loss and fragmentation, and human-caused mortality. As a result, this population is declining at an alarming rate, and without swift intervention by management authorities is at risk of extirpation from the region in the very near future. Our modeling strongly suggests that the annual level of mortality from trapping within the Columbian population of fishers is currently unsustainable and accelerating the declines being seen in this population. Our analysis shows that in addition to the recent closure of the trapping season for fishers in central BC, it is likely necessary to modify the trapping seasons and regulations (including restricting the use of kill traps) for other furbearers found within the range of the Columbian population to reduce mortality from bycatch to give fishers in this region a chance to persist long enough to allow for active habitat recruitment. Additionally, identifying areas where fishers are currently successfully breeding and protecting these habitats from further disturbances will be needed to help increase survival and reproductive rates to levels high enough to reverse population declines over the longer term. Future research should focus on investigating any other management tools aside from regulating trapping and habitat protection that also may be effective in helping to increase survival rates and reproductive outputs within the Columbian population of fishers in BC.

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