

**Bobcat Ecology and Relationship with and influence on Fisher survival on the Hoopa Valley Indian  
Reservation, California**  
**Final Report USFWS TWG CA U-29-NA-1**

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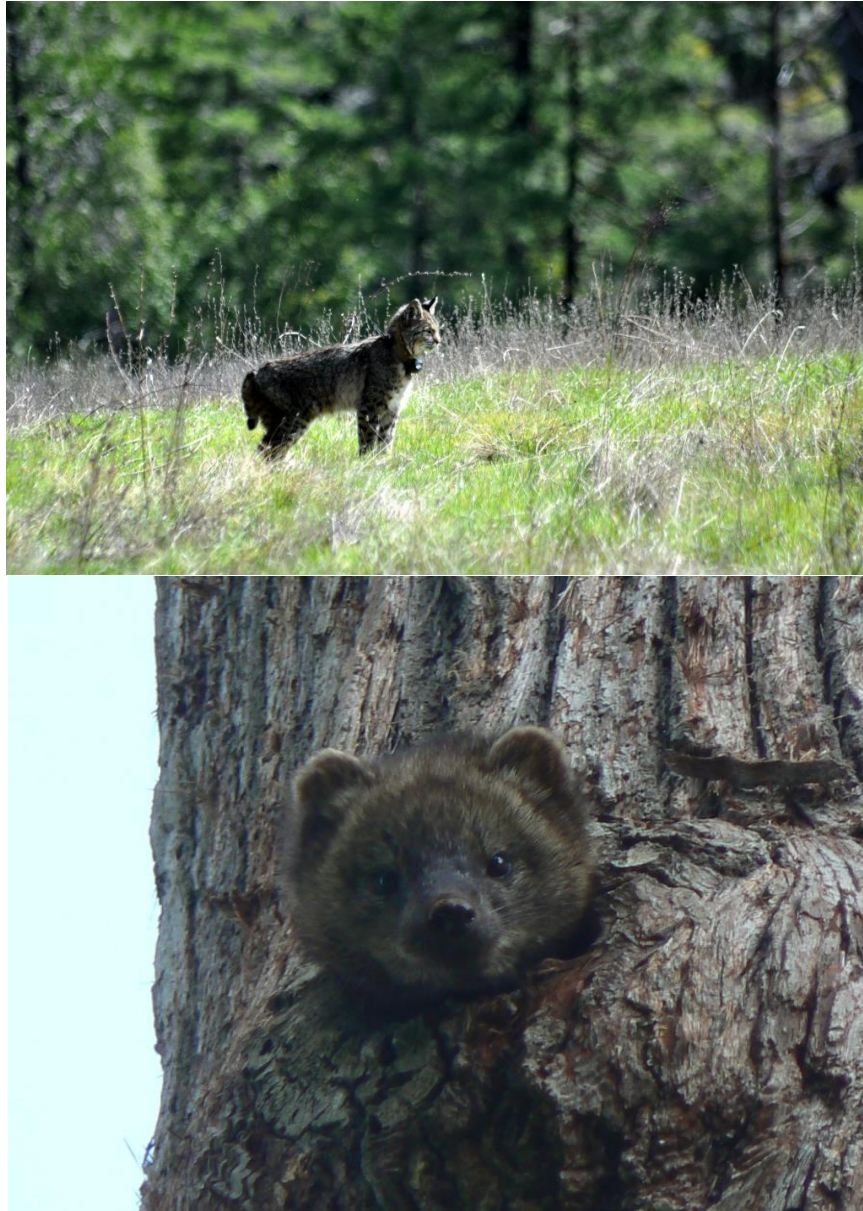
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Top: Female bobcat No. 4. (J. Mark Higley – *Hoopa Valley Tribe*). Bottom: Female fisher 10151 (Kerry Rennie, *Hoopa Valley Tribe*)

Please note the data, analyses, and results reported herein are preliminary and will be reported more fully in future manuscripts. If you find information or ideas contained within this report useful, please consider citing it as: Higley, J.M., G.M. Wengert, S.M. Matthews and K.M. Rennie. 2013. Bobcat Ecology and Relationship with and influence on Fisher survival on the Hoopa Valley Indian Reservation. Final Report USFWS TWG CA U-29-NA-1. Hoopa Valley Tribe. Hoopa, CA.

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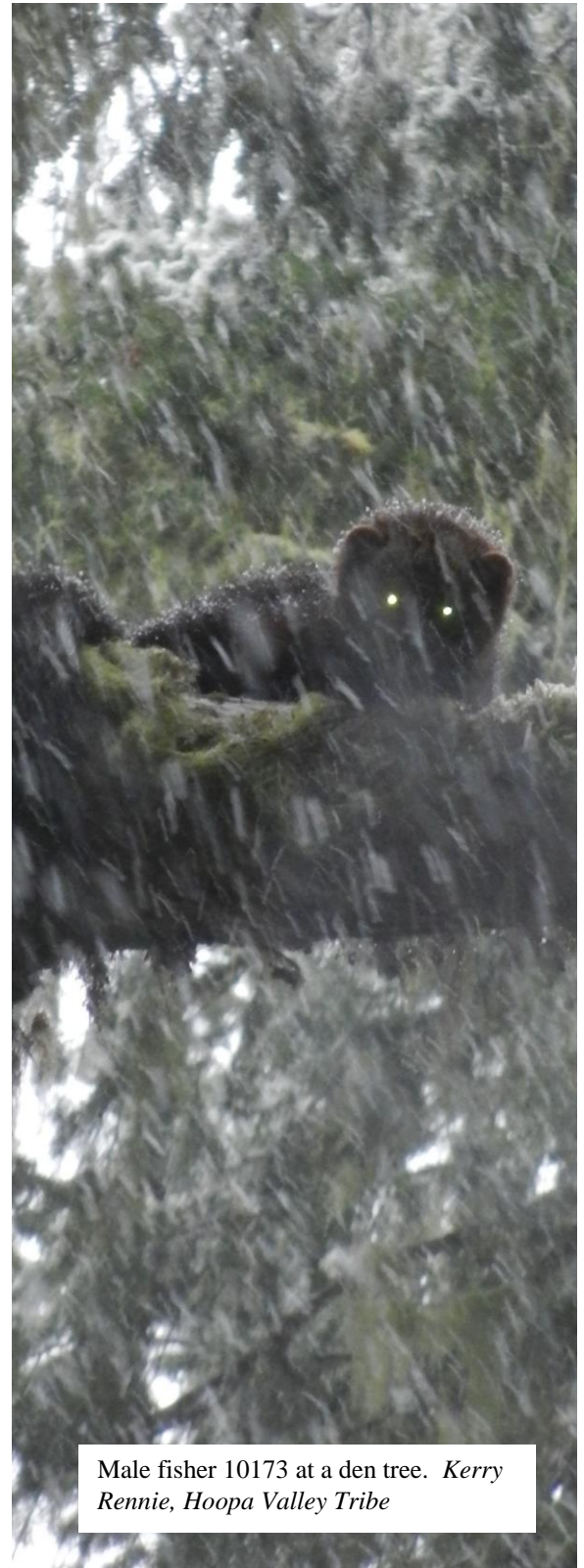
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Female bobcat #3 on a snowy March morning 2012, J. Mark Higley, *Hoopa Valley Tribe*

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Male fisher 10173 at a den tree. *Kerry Rennie, Hoopa Valley Tribe*

## Introduction

The fisher (*Pekania pennanti*) is a mid-sized, forest-dwelling, carnivore in the family Mustelidae. The geographic distribution of fishers historically included the boreal forests of southern Canada, the northern Rocky Mountains, the northeastern and upper-midwestern United States, and southward through the Cascade Range and coastal mountains, northern California, and the western slopes of the Sierra Nevada Range (Gibilisco 1994, Powell and Zielinski 1994, Aubry and Lewis 2003). However, forest management practices and over-trapping for fur during the early twentieth century resulted in population declines and range contractions throughout Washington, Oregon, and California and led to the isolation of populations of fisher in the southern Sierra Nevada Mountains, Northern California, and Southern Oregon (United States Fish and Wildlife Service 2004). In recognition of these declines and existing pressures on current populations, the U.S. Fish and Wildlife Service concluded the “distinct population segment” (DPS) historically occurring in Washington, Oregon, and California was warranted but precluded for listing under the Endangered Species Act (U.S. Fish and Wildlife Service 2004). However, the population density of fishers in some habitats of northwestern California remained relatively high, affording a unique opportunity to investigate poorly understood elements of fisher ecology in the Pacific states (Yaeger 2005, J.M. Higley, Hoopa Tribal Forestry, unpublished data). Upon starting this study in November 2004, it became very obvious that the fisher population had declined significantly since the end of our previous telemetry study in 1998. We repeated a mark re-sight population density estimation in the same area as one that had been conducted in 1998 and found that the density had indeed declined by 73% (Matthews et al. 2011).

The current study was undertaken to 1) Identify sources of fisher mortality and confirm predator species killing fishers, 2) Investigate habitat characteristics associated with fisher predation sites 3) Determine bobcat (*Lynx rufus*) habitat selection at the home range and patch (or stand) level, (4) Determine degree of overlap in habitat use between bobcats and fishers and attempt to model high risk habitats for fishers, and (5) Investigate fisher habitat fitness potential using the demographic data and habitat covariates.

Assessing the viability of existing fisher populations within the range of the Pacific DPS is critical to any management strategy aimed at their recovery. Of particular importance in understanding population viability are survival and reproductive rates (Zeilinski et al. 1999, Franklin et al. 2000). Determining demographic rates requires intensive, long-term demographic studies such as those of northern spotted owls (*Strix occidentalis caurina*) (Forsman et al. 2011, Anthony et al. 2006, Franklin et al. 2000).

Developing a long term monitoring program at a large scale is clearly necessary if we want to understand the relationships between mesocarnivore populations and habitat conditions which are influenced by management, natural disturbance processes or both. Trends in fisher populations across whole regions could likely be accomplished using occupancy survey based approaches similar to those proposed by Zielinski and Stauffer (1996) and Zielinski et al (1997). In addition, an occupancy framework can be used to model landscape scale habitat suitability for fishers (Zielinski et al. 2010, Davis et al. 2007, Carroll et al. 1999). However, including a capture-mark-recapture element to monitoring could significantly improve our understanding of the mechanisms influencing changes in the population.

A capture-mark-recapture (CMR) framework has been used effectively to estimate demographic parameters as well as model individual habitat covariates to investigate elements of habitat fitness potential of northern spotted owls (Franklin et al. 2000, Dugger et al. 2005). Our experience with such northern spotted owl efforts at Hoopa prompted us to design a CMR study for fishers while at the same time collecting known fate (KF) data so that we could compare results and evaluate the potential of the CMR design for a long term monitoring effort.

At Hoopa we had gained experience with fisher capture and recapture rates during the course of a radio telemetry study conducted from 1996-1998 (Yaeger 2005). We captured and marked 56 individuals while attempting to replace radio collars every 6-9 months and found that recapture rates were remarkably high (unpublished data). The current study began in November 2004 and from the beginning we set out to collect CMR data with each trapping effort in the event that we secured funding for additional years of study. At this time we have 9 years of CMR data and up to 8 years (females only) of known fate

monitoring data. We had set up our radio telemetry study in such a way as to provide a dataset for KF analysis. Our vision was to make a comparison between the CMR and KF monitoring to evaluate the feasibility of a long term CMR fisher monitoring effort based on a density study area (DSA).

Having an indication of the age distribution of wildlife populations can be useful for assessing population health and growth potential. This holds especially true for species such as the fisher with relatively low reproductive rates where reproduction does not occur until at least two years of age and average life expectancy is relatively short. In fact, Matthews et al. (2013) documented that 2 year old females were less likely to den and wean kits. Therefore, an age distribution showing a low percentage of reproductive-age females might be a cause for concern. Additionally, reproductive potential and annual variation in reproductive output could both be very important components of population fitness. Therefore, we have documented the age structure of the population on an annual basis.

Determining the causes of mortality and when applicable the predator responsible can improve our understanding and interpretation of demographic rates. Bobcat predation for example, might influence fisher populations in northern CA and could be directly related to human caused habitat alterations. Disease may be generally unimportant but then nearly catastrophic during a major outbreak or when exacerbated by human related elements such as habitat alternation or pollution. Our previous work suggested that predation was an important component of fisher mortality and in particular bobcat predation on female fishers might have the potential to impact the population. With this study we furthered our investigation of the relationship between bobcats and fishers by including a bobcat habitat use and selection aspect within the area where we have been studying fishers.

## **Study area**

The study was conducted within the 367-km<sup>2</sup> Hoopa Valley Reservation in northwest California. The area was located within the Klamath physiographic province (Küchler 1977)(Figure 1). Forests generally had an overstory dominated by Douglas-fir (*Pseudotsuga menziesii*) and a midstory dominated by hardwood trees including tanoak (*Notholithocarpus densiflorus*), madrone (*Arbutus menziesii*) and canyon live oak (*Quercus chrysolepis*). Hardwood stands occurred in some areas and at higher elevations

the Douglas-fir canopy is replaced by white fir (*Abies concolor*) and pine (*Pinus* spp.). The reservation is split by the Trinity River into east and west portions and intensive trapping and telemetry were conducted on both sides of the river (Figure 2).

Past and current timber harvests have created a mix of mature-old growth forest and early seral forest. Prior to 1990 clearcuts averaged 12-20 ha although cuts up to 276 ha occurred. From 1960 to 1980 30% of the reservation was harvested, averaging over 500 ha cut per year. Since 1994 harvest has been implemented under the Tribes Forest Management Plan. The Tribe's current forest management program includes timber harvesting of 9.85 million board feet on approximately 150 ha annually, pre-commercial thinning of approximately 165 ha, early release of 100-175 ha, and cultural burning of 6-40 hectares. Most recent logging was implemented using regeneration methods with green tree and snag retention on small (<10 ha) modified clearcuts or larger group shelterwood cuts. A minor amount of commercial thinning, single tree and group selection was also employed. The history of timber management and wildfires has created a diverse landscape of varying seral stages on and immediately surrounding reservation (Figure 3).

## **Methods**

### Capture and handling: Fishers

Capture and handling methods were approved by the Institutional Animal Care and Use Committee of Humboldt State University, protocol 04104.W.42.A. Fishers were captured in wire mesh live traps (81 x 25 x 31cm) (model 207, Tomahawk Live Trap Company, Tomahawk, Wisconsin, USA) baited with chicken during the months of November to March (2004-2005) or September through March in all subsequent years through 2012-2013. Traps were not set during spring and early summer to avoid capture of lactating females or young kits. Traps were attached to wooden nest boxes to provide security, reduce environmental stressors, and facilitate handling of trapped animals (Seglund 1995, Gabriel and Wengert 2005). Body weight of trapped fishers was visually estimated to the nearest 0.2 kg before fishers were anesthetized with ketamine (40 mg/kg) and Diazepam (0.25 mg/kg) (Aubry and Raley 1996, Yaeger 2005). Fishers were handled using standard protocols that included use of a handling cone (Aubry and

Raley 1996, Yaeger 2005). Each anesthetized fisher was maintained in lateral recumbency in order to stimulate blood circulation and avoid adverse post-capture effects. A brief physical exam was performed to identify injuries. Vital rates of anesthetized animals were monitored continuously throughout anesthesia.

Anesthetized fishers were injected with a sterile 134.2 kHz passive integrated transponder (PIT tag, 134.2 kHz Super Tag, Sterile, Biomark, Inc., Boise, ID, USA). All adult and sub-adult female fisher were fitted with radio transmitters (Holohil model MI-2, Holohil Systems Ltd., Carp, Ontario, Canada) in order to track their movements, identify den sites, and monitor survival. Radio transmitters included either an activity processor (2004-2009) or a mortality sensor (2010-2013). A first-upper premolar was removed for aging by cementum annuli (Matson's Laboratory, Milltown, Montana) (Strickland et al. 1982, Arthur et al. 1992, Poole et al. 1994). All fishers were released after recovery from anesthesia at their sites of capture.

#### Capture and handling: Bobcats

We captured bobcats between October 2010 and March 29, 2012 using Nos. 1 ½ and 1 ¾ Soft-catch foot-hold traps (Oneida Victor® Inc., Euclid, OH), and cage-traps (Homesteader Deluxe 42D, Tru-catch Traps, Belle Fourche, SD) baited with live ring-necked doves (*Streptopelia capicola*), or visual and scent lures with no live bait. Traps were placed opportunistically in areas with recent bobcat sign or sightings prioritized, and/ or target areas where several fishers were already being monitored (Figure 7).

We immobilized trapped bobcats with an intramuscular injection of 10 mg/kg ketamine hydrochloride and 2 mg/kg xylazine. We inserted a passive integrated transponder into each bobcat for permanent identification, took biological samples for genetic and health analyses, took morphometric measurements, and attached to each bobcat one of three types of tracking collars: Quantum 4000 Enhanced Medium GPS Collar with VHF beacons (Telemetry Solutions, Concord, California, USA), Tellus Ultralight GPS collars with VHF beacons (Followit AB, Stockholm, Sweden) and VHF-collars

(Holohil Systems Ltd., Carp, Ontario, Canada). All GPS collars were scheduled to attempt a GPS fix every 4 hours; in addition, they attempted a fix every two hours on every fourteenth day.

#### Aging Fishers

Fishers were assumed to be born on 1 March for known fate monitoring and mark re-capture analysis. Ages were determined by cementum annuli (Matson's Laboratory, Milltown, Montana) (Strickland et al. 1982, Arthur et al. 1992, Poole et al. 1994). Age distribution data was based on the age of animals known to be alive between 1 September and 1 March each year, with animals advancing in age on 1 March. Therefore, an animal born in March 2004 would be 0 years old for the year 2004-05 so long as it was confirmed to be alive sometime between 1 Sept 2004 and the last day of Feb 2005 by either live capture or radio monitoring. For purposes of investigating the age structure of the population through time we established 5 age classes; Juvenile (<1 year), Sub-Adult (1 year), Young adult (2 and 3 years), Adult (4-6) and Old Adult (>6 years).

#### Radio telemetry: Fishers

Telemetry was used to monitor the fate of animals and to identify den and structures as well as documenting active locations. All radio marked animals were monitored at least once per week outside of the den season and 3-5 days per week during the den season from the ground with the use of TR4 (Telonics, Mesa, AZ, USA) or R1000 (Communications Specialists, Inc., Orange, CA, USA) handheld telemetry receivers and 4-element RA-14 antennas (Telonics, Mesa, AZ, USA).

The use of telemetry also allowed for the investigation of causes of mortality. Prior to the use of mortality sensors we attempted to check on every animal that was determined to be inactive the following day if no activity sensor variation had been confirmed. If the animal remained inactive in the same location for 2 visits in a row then homing was used to attempt to locate the collar and determine if the animals was alive or dead. The use of mortality sensors greatly improved the recovery of carcasses in a condition conducive to determine cause of mortality.

Once carcasses were recovered the carcass and the location where the carcass was discovered were photographed in the field and notes were taken to assist with determining the cause of mortality. As the



study progressed it became apparent that we could improve on our field methods for the collection of the carcass and field data associated with mortalities and we began to implement a field-based forensic sample collection protocol starting in 2007 (Wengert et al. *in press*). Carcasses were double-bagged in plastic bags, labeled, and transported back to the office where they were frozen in a -20C freezer until being shipped to University of California Davis for further analysis. We performed necropsies on all available fisher carcasses either at the University of California Davis, Veterinary Medical Teaching Hospital or California Animal Health and Food Safety Laboratory, Davis, CA. When possible, we determined cause of death for each fisher (identified as “Confirmed”). For animals that were recovered prior to 2007 or those for which only pieces or fragments were found, we estimated the suspected cause of mortality (identified as “Suspected”). Using either method we occasionally arrived at the determination that the cause of death was undeterminable or “unknown”. Predation was confirmed by ante-mortem hemorrhaging at the location of puncture wounds and sufficient damage to conclude that the wounds would have been fatal. After implementing the forensic protocol we also used molecular methods to determine the predator of each fisher Wengert et al. (2013).

#### Radio telemetry: Bobcats

In addition to GPS location data, we monitored bobcats at least once per week with the use of TR4 (Telonics, Mesa, AZ, USA) or R1000 (Communications Specialists, Inc., Orange, CA, USA) handheld telemetry receivers and 4-element RA-14 antennas (Telonics, Mesa, AZ, USA). Locations were taken from systematic points, with azimuths on a single bobcat being taken within a 20-minute period and with angles  $>20^{\circ}$  of each other to reduce error when bobcats were active. Three or more of these locations were used to estimate location of bobcats through triangulation.

#### Home Range Analysis: Bobcat

We used bobcat locations obtained through telemetry for analyses if observer confidence level for a triangulation was at least level 3 (on an observer designated scale of 1 – 5 where 1 = location not used for any analyses, 2 = animal is likely in watershed, 3 = use location for home range, 4 = use location for habitat analysis, and 5 = animal is likely within 20m of location). We used GPS fix locations for analyses

if HDOP, an index of location error, was 6 or less. We used fixed kernel density methods to calculate home ranges for all bobcats with  $\geq 100$  locations (Powell 2000). We calculated FK home ranges using ad hoc smoothing parameters ( $h_{ad\ hoc}$ ) designed to prevent over- or under-smoothing (Berger and Gese 2007). This method involved choosing the smallest increment of the reference bandwidth ( $h_{ref}$ ) that resulted in a contiguous 95% fixed kernel home range polygon that contained no lacuna (i.e.,  $h_{ad\ hoc} = 0.9 * h_{ref}$ ,  $0.8 * h_{ref}$ , etc.; J.G. Kie, Idaho State University, Pocatello, Idaho, personal communication). FK home ranges were estimated using the Home Range Tools extension (HRT; Rogers et al. 2007) available for ArcMap 9.3 (Environmental Systems Research Institute, Redlands, California, USA). To estimate the core area for each fisher, we computed the sizes of 19 FK isopleths using  $h_{ad\ hoc}$  containing from 5-95% of the observations in increments of 5% (Seaman and Powell 1990, Bingham and Noon 1997). We used these isopleths in regression analyses to identify the home range isopleth in which use exceeded that expected under a null model of a uniform distribution of locations (Bingham and Noon 1997). We described second order habitat use (Johnson 1980) as a simple percentage of the 95% fixed kernel home ranges and core areas represented by each habitat strata type.

### Bobcat Habitat Selection

For all habitat analyses, we used ArcGIS 9.3 (ESRI, Redlands, CA) and a habitat map extending across the study area (Hoopa Valley Indian Reservation buffered by 3200m). The habitat map was developed by the Hoopa Tribal Forestry Department and attempted to stratify HVIR lands into polygons of different habitats types > 3 acres. The map originally consisted of 3570 unique types consisting of different values for plant species, canopy height and canopy density classes for up to four canopy layers within a single type. These types were grouped to present a more manageable number of unique habitat types. For this project, adjustments were made to create a group of seven habitat strata likely to be most relevant to an analysis of bobcat and fisher habitat use (Table 1).

We estimated second-order and third-order habitat selection for bobcats (Johnson 1980). We estimated second-order habitat selection for both 95% FK and core areas of each bobcat using

compositional analysis (Aebischer et al. 1993) with the Adehabitat package (Calenge 2006) which compares habitat use to availability. We calculated the percent of each bobcat's 95% FK and core area comprised by the different habitat strata and compared them to availability of habitat types across the study area (the Reservation buffered by 3200 m) (Table 1).

We estimated third-order habitat selection three ways. First, we used compositional analysis to compare the percent of locations for each bobcat that fell into a particular habitat strata type to the percent of each bobcat's corresponding home range comprised by the different habitat strata types. Second, we calculated individual habitat selection indices for each bobcat using a standard resource selection index  $[(\text{Observed} - \text{Expected})/\sqrt{\text{Expected}}]$ . Observed values were the proportion of all bobcat locations falling within a particular habitat types and expected values were the proportions of that habitat type composing that bobcat's home range. Index values fell between -1 and +1, where negative values represent selection against a habitat type, and positive values represent selection for a habitat type.

Third, we used a case-control logistic regression approach. We used 3525 bobcat locations from the seven collared bobcats to represent "used" locations. We then created random points throughout each bobcat's 95% fixed kernel equal to the number of "used" points for each individual bobcat to represent "available" habitat using Hawth's Tools for ArcGIS 9 (Beyer 2004). We coded each bobcat location and each random point according to habitat type (STRATA), forest cover (FOR/NONFOR), management scheme (UNMAN, CABLE, TRACTOR), distance to road (both drivable, DRVROAD and non-drivable, NODRVROAD), and distance to nearest edge (edge between any two habitat strata, EDGE, and edge between forest and non-forest types, HRDEDGE) from each location (Table 1). All spatial analyses were completed using ArcGIS 9.3 (ESRI, Redlands, CA).

We used generalized linear mixed models logistic regression fit by the Laplace approximation (Bolker et al. 2009). We included individual bobcat as a random effect to block for individual bobcat differences in habitat use, unbalanced sample sizes among bobcats, and differences in availability of habitats for each bobcat (Gillies 2006). We created dummy variables for the habitat strata, forest, and

management scheme categorical variables. We checked for multicollinearity among our variables using variance inflation factors (VIF), and did not use variables in the same models when  $VIF \geq 10$ .

#### Habitat in Areas of Fisher and Bobcat Overlap

To describe habitats where fishers and bobcats would be more likely to encounter each other, we analyzed habitat features in areas of overlap between the two species. We defined overlap as regions that fell within both the 95% fixed kernels for individual fishers and within one or more core areas of bobcats that were tracked during the same period. We used only female fishers because no males were documented to have been killed by bobcats in California. We quantified composition of these overlap and non-overlap areas as described above.

We conducted univariate statistics for analysis of habitat variables between regions of overlap and non-overlap for fishers and bobcats using paired *t*-tests. We then used generalized linear mixed models logistic regression fit by the Laplace approximation (Bolker et al. 2009). We included individual as a random effect to block for individual fisher differences in habitat use and unbalanced sample sizes among fishers (Gillies 2006). We checked for multicollinearity among our variables using variance inflation factors (VIF), and did not use variables in the same models when  $VIF \geq 10$ .

#### Spatial Predation Risk Using Predation Sites

We recovered deceased fishers from the field, conducted necropsies when possible, and determined predator species using forensic molecular analysis (Wengert et al. 2013) or classification and regression methods to assess the predator species based on physical characteristics of the predation event (Wengert 2013). We used the results of the bobcat habitat selection analyses and bobcat-fisher habitat overlap analysis to choose the habitat variables most associated with bobcat presence to form hypotheses about habitats associated with fisher predation sites. We coded all sites where fishers were killed by bobcats and all available telemetry locations for each of these predated fishers with these habitat variables

and performed a *t*-test for each to test our predictions about differences in habitat variables between predation sites and live-fisher locations.

### Statistical Analysis

We conducted T-tests and Chi-square analyses to assess differences in means of habitat variables between bobcat used and unused locations, and between fisher risk and non-risk points. We built logistic regression models for bobcat third order habitat selection (Johnson 1980), high risk habitat for fisher predation, and high risk habitat specifically for female fisher predation using the variables described above and in Table 1. We used Akaike's Information Criterion to select the best models. All statistical analyses were conducted using R version 2.14.1 (R Development Core Team 2010).

### Fisher Known fate monitoring: Fisher

We attempted to monitor all radio collared animals weekly including confirmation that each animal was alive and obtaining a location, either triangulation or homing in on resting animals. For analysis purposes we used months as occasions and confirmed status at the beginning and end of each month. Censoring occurred for animals when collars dropped off, failed or when the animals no longer could be found. Most of the animals lost from the air without finding collars were believed to have experienced collar failure and/or potentially dispersed. In 2006 we had a large number of collar failures due to the chip sets coming loose. Nearly all of the collars deployed that year were replaced later in that season as the problem was identified early on and the manufacturer offered to replace the collars. A few animals, primarily juveniles disappeared from the air and were not recaptured. All of the non-juveniles that experienced collar failure were recaptured and their collars replaced. Three males had their collars removed because they had become too tight and affected the skin on their necks. All 3 were subsequently recaptured and collared at a later date during the same capture season. Many of the animals censored returned to the study during the following capture season. There was no reason to believe that animals lost from the air or dropping collars and not being recaptured at a later date would have survived or died at a different rate than those that were continually monitored. Animals entered the study at different times

within each capture year and new animals were added each year.

Males were only a small part of the sample at the beginning of the study and male known fate data was too sparse to include in the analysis until the year 2008-09 and on to the end of the study (2012-13). The main purpose of the addition of the males was to include males in the habitat selection analysis at the home range level and to provide data for an analysis of gender specific survival rates within the study area. Therefore, we targeted non-juvenile (post dispersal) males to ensure that there would be a high likelihood of them using the study area so that we could effectively track their habitat use and survival. Females were added to the study as they were captured without set criteria until we had as many animals collared as we were confident we could track each year. We did however, avoid juveniles in later years when there were plenty of non-juvenile animals within the study area. We attempted to monitor 15-25 females and 10-15 males each year.

The data were grouped by “fisher years” beginning with March 1 and ending at the end of February to coinciding with the birth or increasing of age of each animal. We completed several different analyses with the known fate data.

- 1) A comparison of monthly and annual survival rates between genders with 5 years of data (2008-09 to 2012-13).
- 2) Analysis of female survival using 8 years of data (2005-06 to 2012-13).
- 3) Analysis of male survival using 5 years of data (2005-06 to 2012-13)
- 4) Analysis of female survival using 8 years of data (2005-06 to 2012-13) with habitat covariates.

Juvenile data was too sparse to be of use as a grouping variable or covariate for all but the first 5 years of female data. We made an effort to investigate differences in juvenile and non-juvenile female survival using those 5 years but then dropped the analysis from further consideration for 2 reasons; 1) Very few juveniles monitored for only 1-6 months each year, and 2) those juveniles clearly survived at or above the rate of the non-juveniles during the 1-6 month periods so no need to drop them or treat them differently in the larger analysis. Therefore, we chose to leave the juvenile females in all of the known fate analysis except that with the habitat covariates since the juveniles were often in dispersal mode and

not settled into home ranges. For the first 3 analyses we used years as grouping variables where there was an encounter history record for each animal in each year. Therefore, animals could have been included multiple times within the data set with an annual record including 12 occasions (months) each year that they were monitored similar to Gosselink et al. (2007). This allowed for treating years as groups for the purpose of investigating differences between annual survival rates. Many animals were in fact included in several year groups and a few up to 8 times having been monitored continuously through the entire study.

For the fourth analysis with habitat covariates we included a single record for each female monitored which included her non-juvenile monitoring period and a list of habitat covariates (Table 2). This data set included 96 occasions and up to 88 covariates. We chose to use this approach coupled with a life of monitoring fixed kernel home range for use in calculating the habitat covariates rather than attempting to calculate annual home ranges. We felt this was the best approach for our data given that there would have been many animals with one or more years where there would not have been sufficient locations to generate a meaningful home range. This scenario would occur for several reasons including time of capture and entry into the study (late in capture season), the death of an animal early in a “fisher year”, or loss from the air due to dropping or failing collars.

#### Fisher Home Range Analysis

For the purpose of generating habitat covariates for use in the known fate survival analysis we generated fixed kernel home ranges. We estimated size and location of home ranges for non-juvenile female fishers with  $\geq 20$  locations. We used the 95% isopleths of the utilization distribution generated from the fixed kernel method (FK; Kie et al. 1996, Seaman et al. 1999) with an ad hoc smoothing parameter ( $h_{ad\ hoc}$ ) using Home Range Tools (HRT; Rogers et al. 2007) for ArcGIS 9.3 (ESRI 2008). This method involved choosing the smallest increment of the reference bandwidth ( $h_{ref}$ ) that resulted in a contiguous 95% kernel home range polygon that contained no lacuna (i.e.,  $h_{ad\ hoc} = 0.9 * h_{ref}, 0.8 * h_{ref}$ , etc.) (Berger and Gese 2007, Jacques et al. 2009). We empirically estimated core areas for each home range following methods outlined by Bingham and Noon (1997).

The female home range polygons including 95% fixed kernel and the core use area, were then intersected with habitat strata maps, management and roads GIS layers. Habitat strata layers included as many as 6 strata types or as few as 2 (Figures 4 and 5). Management strata included up to 3 categories including un-managed, tractor logged, or cable logged and then simply managed and un-managed. Roads were classified as drivable, non-drivable and total density (meters per hectare). The various strata and roads data were derived from the Hoopa Tribe's GIS databases (TYPE, HUPAVEG, and ROADS). The Hupaveg layer is a vegetation layer that was created by GIS analyst Jimmy Campbell and biologist Mark Higley using historic management layers and intensive editing of all polygons including line work and attributing up to 12 fields of data. The coverage includes 5,668 unique polygons representing 3,585 unique type codes. These type codes have been stratified into 15 stand structural stages based on a modification of Oliver and Larson (1996) (Figure 3). The stand structural stages were then stratified into 6 strata representing primarily seral stages but including a catch all strata for the vegetative class true oak woodlands of all stand age classes and open non-forested areas lumped with seedling stage stands (Table 2). We used Fragstats (McGarigal et al. 2002) to generate the habitat strata covariates. This allowed for the calculation of a number of fragmentation and spatial arrangement indices (Table 2). For areas outside of the Reservation boundary an additional habitat strata layer was created in much the same way as the on reservation portion except that each polygon was simply assigned a stand structural stage class rather than the intensive attributing that occurred for the on-reservation portion. One additional covariate was created by measuring the distance between the geometric center of each female home range and the closest edge of an Urban zone interface.

All survival analysis was completed with program MARK (White and Burnham 1999) using known fate models allowing for a staggered entry design (Pollock et al. 1989).

#### Capture Mark Recapture: Fisher

Capture-Mark-Recapture (CMR) data was collected from 2004-05 to 2012-13. Trapping occurred between September and early March each year, except 2004 when trapping did not begin until late November. Trapping ended in early March to avoid capture of females nearing parturition. The



fisher study area was identified prior to the 2004-05 trapping effort but later modified. It became obvious that the population was not nearly as dense as it had been in 1996-99 and we had to increase the trapping area in order to approach the 15-20 females that we were targeting for radio collars with our initial effort. In all subsequent years we trapped the same CMR trapping area with mostly the same trap sites as that which were established in 2004-05 (Figure 2). We attempted to trap the entire area with equal effort each year. We systematically moved traps around covering 15-25% of the area for 3-4 weeks at a time and then moving to the next area. Typically we alternated sides of the Trinity River, trapping only one side at a time most of the time but occasionally trapping both sides at once. Areas trapped at the beginning of the season were re-visited later in the season since we have found trapping success to improve throughout the season, being best during periods of inclement weather and during times when bears are least active. This provided 4-7 weeks of trapping effort in each trapping area throughout the entire CMR study area each year. Within season occasions were based on 1 week intervals.

All analysis of the mark recapture data was completed using program MARK (White and Burnham 1999) and employing the “Closed Captures,” “Recaptures Only” and “Pradel Models” for population estimation, apparent survival and lambda respectively. Juvenile animals were excluded from the analysis designed to estimate apparent survival since we expected that many of them would disperse (emigrate) away from the study area and therefore not be available for subsequent recapture, hence biasing the estimates of apparent survival low. Datasets for apparent survival therefore did not include any captures of juvenile animals even if they were subsequently recaptured as non-juveniles. Those animals first captured as juveniles were simply not counted as captured in their juvenile year. Similarly we were concerned that animals captured on the fringes of the study area would have lower recapture probabilities than those of animals captured within the core of the trapping area. We therefore included a covariate indicating that animals were or were not ever captured in core traps. Animals captured in at least 1 core trap were coded as “1” while those only captured in fringe traps were coded as “0” in the apparent survival analysis.

Juvenile animals were retained in the input files for both annual population and lambda

estimation. Not doing so would have severely biased the data low in some years and not as badly in others making it very difficult to interpret the results.

Fringe trap sites were determined based on two factors, 1) proximity to the boundary of the study area and landscape features likely to form home range boundaries, and 2) amount of trapping effort given to the sites each year (Figure 2). Many trap sites were also used over the years that fell outside of the CMR trap area for the purposes of targeting radio collared animals for collar replacement or removal. Animals captured in only non-CMR traps were not counted as captured within any of the CMR analysis. This also included fishers captured in bobcat traps unless the bobcat trap was inside the CMR trapping area during our normal trapping sessions.

The main purpose of the mark recapture analysis was to determine the feasibility of monitoring the reservation fisher population demographic rates with this approach and to compare the results to those of the known fate method. The mark recapture survival model results were used to investigate whether there appears to be a difference in apparent survival between sexes and to compare results to those of the presumably more accurate and more precise known fate models. In addition, the female CMR survival data was also ran with habitat covariates similar to the known fate analysis.

In order to generate habitat covariates for the female CMR survival analysis we calculated a mean center point using all the capture locations of each female across all of the years. For animals captured only once that location was used as the center point. Then the points were buffered by 3000 meters and 1900 meters to represent the landscape and home range scale respectively. The 3000 meter buffers were either left fully in-tact or truncated by the edge of the urban zone or the Trinity River. The urban zone is inherently unsuitable fisher habitat and the river forms a barrier that has not been crossed by any non-juvenile fisher since the beginning of our radio telemetry studies. The area within the 3000 meter buffers ranged from 840 to 1134 ha and averaged 1094 ha (Figure 6). We arrived at the buffer size by calculating the mean maximum distance moved for female fishers based on our telemetry data and then evaluated the buffers ability to represent the home range and immediate surrounding landscape of female fishers using the sample of females that had enough radio telemetry data to provide estimates of home ranges. Using

the 95% fixed kernel home ranges for the 44 females from the known fate data that were represented in the CMR dataset, we estimated how inclusive our 3000 m buffers were in terms of representing entire female home ranges and the landscape surrounding them.

The buffers were then intersected with the habitat strata, management and roads layers similar to the effort described above for the known fate habitat covariates using the fixed kernel home ranges. For the CMR analysis we, however, included fewer total covariates given the less precise nature of the buffer data compared to the home range data and having completed the known fate analysis first we could eliminate many covariates that showed little or no promise.

## **Results**

### **Bobcat capture, telemetry and home range**

Seven bobcats (4 male, 3 female) were captured 9 times between 6, February 2011 and 14, February 2012. All three female bobcats and three of the male bobcats were equipped with a Quantum 4000 Enhanced Medium GPS Collar with a VHF beacon (Telemetry Solutions, Concord, California, USA). One male bobcat was equipped with a VHF-collar (Holohil Systems Ltd., Carp, Ontario, Canada) for a full year, then re-captured and equipped with a Tellus Ultralight GPS collar with a VHF beacon (Followit AB, Stockholm, Sweden). We monitored individual bobcats between 2 – 20 months and GPS collar fix rate ranged from 35.6% to 73.8% of all attempts. We obtained between 141 and 953 independent and usable locations (meeting our criteria for inclusion based on error) from each of the seven bobcats. Additional capture effort from March 2012 to February 2013 resulted in no bobcat captures.

Bobcat 95% fixed kernels ranged from 11.1 km<sup>2</sup> to 18.3 km<sup>2</sup> with a mean of 14.4 km<sup>2</sup> (3.6 km<sup>2</sup> SD) for females and 13.7 km<sup>2</sup> to 92.0 km<sup>2</sup> with a mean of 57.6 km<sup>2</sup> (35.2 km<sup>2</sup> SD) for males (Table 3 and Figure 8). Bobcat core areas were either 60% ( $n=6$ ) or 70% ( $n=1$ ) fixed kernels and ranged from 3.1 km<sup>2</sup> to 4.1 km<sup>2</sup> with a mean of 3.9 km<sup>2</sup> (0.2 km<sup>2</sup> SD) for females and 4.6 km<sup>2</sup> to 25.3 km<sup>2</sup> with a mean of 17.2 km<sup>2</sup> (9.4 km<sup>2</sup> SD) for males.

### Bobcat habitat selection

Proportions of 95% FK and core areas composed by different habitat types were on average very similar to the composition of the study area overall (Table 4, Figure 3). However, the compositional analysis indicated a marginally significant selection of certain habitat types by bobcats (Wilk's  $\lambda = 0.00158$ ,  $P=0.058$ ). This analysis indicated bobcats selected for YFM, BRUSH, YCCF, and OPEN, and selected against MOF, OPSHRB, and TOW at the home range scale. For the core areas, selection for any particular habitat type was not significant (Wilk's  $\lambda = 0.06887$ ,  $P=0.609$ ), although OPEN habitats were selected over MOF in core areas.

For third-order habitat selection, compositional analysis indicated a strong selection for OPEN, BRUSH, and OPSHRB habitat types, which collectively represented non-forested habitats, and selection against MOF, YFM, and YCCF, the forested habitats (Wilk's  $\lambda = 0.000086$ ,  $P=0.024$ ). The habitat type TOW was neither selected for or against in relation to the other habitat types. Habitat selection indices were strongly positive for OPEN for five of seven bobcats, positive for BRUSH for five of seven bobcats, and negative for MOF and YFM for six of seven bobcats (Figure 9). All bobcats selected against YCCF (Figure 4).

There were differences in some variables between used and available bobcat locations, most notably in BRUSH, MOF, OPEN and YCCF (Table 5). Habitat strata, distance to any type of road, and distance to any type of edge were included in the model that best predicted bobcat third-order habitat selection (Tables 6 and 7). The only other competing model included habitat strata, distance to any type of road, and hard edge specifically (Table 6). Likelihood of bobcat occurrence increased in OPEN (odds ratio [OR] = 2.9068) and BRUSH (OR = 1.8453), while it decreased in MOF (OR = 0.3653), YCCF (OR = 0.3815), and YFM (OR = 0.4404)(Table 7).

*Habitat in Areas of Fisher and Bobcat Overlap.* We had fifteen fishers whose home ranges overlapped at least one bobcat's core area. Average habitat composition was similar between these overlap areas and portions of fisher home ranges not overlapping bobcat cores

(Table 8). The best model describing overlap of fisher kernels and bobcat core areas included density of non-driveable road (NODRVROAD), proportion consisting of young, multi-storied forest (YFM), and proportion consisting of open habitats (OPEN, Tables 9 and 10). Decrease in NODRVROAD density and increase in amount of open habitats significantly increased the odds of fisher and bobcat overlap (Table 10).

*Spatial Predation Risk.* We attributed eleven female fisher deaths to bobcat or lion predation (Figure 10). Based on the previous analyses of bobcat habitat selection, which consistently indicated OPEN and BRUSH habitats were selected for by bobcats, we predicted that fisher predation sites would be closer than expected by chance to these habitats. Indeed, these predation sites tended to be closer to the edge of OPEN or BRUSH habitats (average = 212.3 m, SE = 37.2 m) than live-fisher locations (average = 339.9m, SE = 7.5;  $t = 3.0128$ ,  $df = 9.835$ ,  $P = 0.006645$ ).

#### Known fate monitoring and causes of mortality

One hundred and ten fishers (39 male, 71 female) were radio collared between Dec. 2004 and March 2013. The known fate data collected through the monitoring of these animals has been analyzed in 4 different ways including 4 different datasets (Tables 14 and 15). Of these 110 individuals, 48 were monitored until they died (17M, 31F). Average age at death across all years and all ages was 4.1 and 4.8 years for males and females respectively. Comparing the mean age at time of death of females for the years 2005-2008 ( $n=19$ ) and 2009 to 2012 ( $n=12$ ) there has been an increase in age from 3.8 to 6.3 years. There were not enough males monitored prior to 2009 to make a similar comparison for males.

Causes of mortality were similar for males and females but in different proportions and males succumbed to one confirmed cause of mortality (toxicosis) that was not confirmed for females (Tables 16 and 17). Predation was by far the most important cause of mortality for females throughout the study with 64.5% of all female mortalities either confirmed or suspected to be predation (Table 17). However, predation appears to have dropped somewhat between the first half of the study and the last half while

mortalities from disease have increased (Table 17). Males have also died from predation but at less than half the rate of females at 29.4% (Table 17). Of 20 females confirmed or confidently suspected to have been killed by predators, 13 were suspected or confirmed to be killed by bobcats (8 confirmed by molecular methods), 2 by mountain lions, 3 by canids (none confirmed by either) and 2 uncertain. Thirty percent (6 of 20) female predation events occurred in May and 5 of the 6 were killed by bobcats.

Alarming, males have died as a result of toxicosis at the rate of 29.4% (Tables 16 and 17). Disease has caused mortality at similar rates between males and females 17.6% and 22.6% respectively (Table 17). One female fisher (10006) was classified as a disease mortality after she walked into the yard of a local residence and approached a pit bull on a tether. The dog bit and shook her a couple of times and she crawled under a porch and died. Necropsy confirmed that she was suffering from a number of diseases at least one of which had caused lesions in her brain. A slightly higher percentage of male mortalities were undeterminable than females, however, at least one of the male unknowns was potentially a toxicosis case (Tables 16 and 17).

Research related mortalities have occurred in two ways: 1) An adult female fisher was caught in a trap that was not supposed to be set and died from malnutrition and dehydration and 2) a male died when domestic dogs (confirmed with molecular DNA from hair and saliva samples at the site) attacked the live trap he was in and tore it apart and then attacked and killed him.

Suspected or confirmed predators were bobcat (*Lynx rufus*), mountain lion (*Felis concolor*) and unknown canids possibly coyote (*Canis latrans*). Female fishers have likely been killed by all 3 of these predators while males were killed only by mountain lions (4) at Hoopa (Wengert et al. Submitted).

#### Known fate survival

The top ranked model estimating fisher survival for both sexes combined for the period of 2005-06 to 2012-13 carried 36.9% of the AICc weights and included different estimates by sex, grouping of years 1 and 2 for males only and lower monthly survival rates during May and June across all years (Table 18). The sex and May-June effect was included in all of the competitive models while various time trends across years substituted for the year 1 and 2 grouping for males only (Figure 11). Important

throughout all of the competitive models of the first 3 datasets which include monthly occasions and annual groups was the inclusion of a May-June effect on monthly survival, where survival for both sexes is lower during May-June than all of the other months (Figures 12 and 13).

The female only analysis included 8 years of data and generally showed an increasing trend in female survival (Table 19 and Figures 13 and 14). The top model included a downward trend for the years 2005-06 to 2007-08 and constant, higher survival for the period 2008-09 to 2012-13. The second model included constant, lower survival for the years 2005-06 to 2007-08 and constant, higher survival for the period 2008-09 to 2012-13 (Figure 13).

The male only survival results did not differ much from the joint analysis including both sexes and the top 2 models again included either a quadratic time trend (2<sup>nd</sup> model) or constant, lower survival for the years 2005-06 to 2006-07 and higher survival for the years 2008-09 to 2012-13 (Tables 18 and 20). Therefore, the annual estimates and May-June and other month estimates did not differ appreciably from the joint analysis.

#### Female Known Fate Survival with Habitat Covariates

The female only analysis with habitat covariates resulted in more than 10 models that were competitive while no one model carried more than 12% of the AICc weights (Table 21). While no clear top model was identified many models with habitat covariates were above the top model without at least one habitat covariate (Table 21 and Figure 15). Although this is important, it must also be pointed out that because of the configuration of the input data set which included one record for each female and up to 96 possible monthly occasions, it was unlikely that any time varying models would be competitive given that years were not identifiable leaving only a very long string of monthly occasions. That left only a fully time varying model (96 parameters) or constant survival model (1 parameter) available without a covariate.

Although more than 10 models were within 2 AICc points we considered only 5 of the top 6 to be meaningful models based on the betas and our expectations of the effect of the variable (Tables 2 and 21). For example, model 4 included the distance to the urban zone from the mean center point of the 95%

fixed kernel (Table 21). Our expectation was that it would be a negative impact on survival since animals close to the urban zone and human habitation would potentially be exposed to toxicants, increased human disturbance and domestic animals (free ranging dogs especially) potentially contributing to lower survival. However, the betas for the model with distance to urban indicated that survival would decrease as the distance to urban became greater. Therefore, we discounted this model from further evaluation since it appeared to have the opposite effect to our biological expectation and therefore was likely representing some other correlated effect such as percent cover of managed stands or mature and older forest.

The strongest variables, included in all of the competitive models, were the density of drivable roads (DRd) within the core fixed kernel home range and the percent of OPEN strata within the 95% kernel (Table 21). The inclusion of these variables in all of the competitive models ensured relative agreement among the individual survival estimates resulting from each model (Figure 15). In other words each of the models predicted the same individuals to have high, moderate or low survival. The top model included only these 2 variables and carried 11.8% of the AICc weights (Table 21 and Figures 16-18). There were several models among the top 6 that included a positive effect from different forms of percent cover of mature and older forest within the 95% kernel (Table 21 and Figure 17). The 6<sup>th</sup> model included a negative effect of percent cover of stem exclusion stage forest within the 95% kernel (Table 21 and Figure 18). The 4 variables with some apparent influence on female survival varied from individual to individual by varying degrees of magnitude (Figure 19). For example percent OPEN within the 95% kernel ranged from 0.6% to 19.1% and averaged 4.8% with a standard deviation of 4.1 while mature and older forest ranged from 13.3% to 60.0% with a mean of 34.9% and a standard deviation of 10.8. The top models appeared to be heavily influenced by a few animals that died mostly from predation early in the study following very short periods of monitoring and which had substantially higher densities of drivable roads within their core kernel home ranges. This has likely resulted in the steep decline in survival shown in Figures 16-18 for the road density variable. All of the other variables appear to have a much more



subtle influence on female survival although mature and older forest covers a broader range than either OPEN or SX (Figures 16-18).

The relative agreement in estimates of survival among the top models allowed for the development of diagrams representing low, moderate and high survival based on individual home ranges (Figures 20).

#### Capture-mark-recapture population estimation

Two hundred and forty one fishers (130 F, 111 M) were captured and marked during the course of this study. Of those, 221 were used in the CMR dataset (118 F, 103 M) the remainder were captured incidentally while targeting radio collared animals that had left the CMR study area. Annual live capture efforts varied from 1583 to 2423 trap nights and used between 122 to 167 unique trap locations (Table 22). Total capture success rates (including recaptures within season) ranged from 4.3% to 8.1% while new capture rates (total individuals captured within season) ranged from 1.6% to 2.9% (Table 22) across all the years of effort. The total number of females captured annually showed a distinct upward trend while the total number of males was nearly stationary but with signs of decline (Figure 21). After the first 3 years of capture effort the mean age of new individual females captured each year was below 1.5 years of age and frequently below 1.2 years (Figure 21). Mean age of new male individuals was below 1 year of age from the second year on to 2011-12 (Figure 21). This indicates that most resident individuals are likely accounted for in CMR data and that we are not missing many if any males and very few females on an annual basis. This is an important point given that we used the CMR data for estimates of annual population, apparent survival and lambda (rate of population change).

Total and female CMR annual population estimates trended upwards while male estimates were stable to declining (Figure 22). The overall increase in population has resulted in the population density increasing to over half of where it was in 1998 (Figure 23). Two factors may be serving to exaggerate the difference between the 1998 density and the 2012-13 density: 1) the mean maximum distance moved used for the 1998 estimate was generated from trap, camera and telemetry location data just as it has been for the recent data, however, the radio telemetry data was limited primarily to rest, den and active locations

determined by homing rather than triangulation and 2) the population on the east and west side may be recovering at different rates and the current mean maximum distance moved on the east side has increased while on the west side has decreased leaving the overall mean maximum distance moved at a relatively larger value over all than if both sides were calculated separately (Table 23).

#### Mark recapture monitoring – lambda

We ran random effects models to determine estimates of lambda for the population as a whole and for males and females separately (Tables 24 - 26). We chose to do this for 2 reasons. First, the analysis with both sexes had 2 models that were competitive with the top model, one including a Time Trend and one indicating that there was a sex effect (Table 24). Second, the annual population analysis indicated that females were increasing while males were stable to decreasing (Figure 22). In addition, since there are differences in the physical and behavioral characteristics of males and females in several ways such as, body size, home range size and likely habitat selection and possibly prey, the sexes may be subject to different pressures that influence survival and population growth. The estimates for lambda indicate that the population as a whole is essentially stable while males are likely decreasing and females are possibly increasing (Table 27 and Figure 24).

The age structure of the population seems to be changing in different ways with the mean age of females generally increasing while it may be decreasing for males (Figure 25). In addition, the mean age of females is generally near 2.5 years while males are often at or below 2 years (Figure 25). Although the age data for new individuals captured in 2012-13 is unavailable until June 2013, these patterns will likely continue given that more than half of the total male population was comprised of new animals, which generally average lower than 1 year old, while only 1/3 of females were new animals in 2012-13 (Figure 21).

#### Capture-mark-recapture – Apparent Survival

Estimated recapture rates of fishers has shown an increasing trend throughout the study as we have replaced older traps with new ones that function more efficiently and as we have improved trap placement with the use of historical knowledge (Figure 26). Rates at the beginning of the study were

remarkably high (slightly greater than 60%) given that fishers are a rare forest carnivore with relatively large home ranges but they have improved to over 80% (Figure 26). Because several apparent survival models were quite competitive and carried 79.9% of the AICc weights we chose to model average to arrive at estimates of apparent survival (Table 28 and Figure 27). The result indicate that female apparent survival was increasing slightly from 0.73 to 0.82 while male apparent survival was decreasing substantially from 0.68 to 0.46 (Figure 27). There was strong support for different rates between the sexes and for higher female apparent survival across the majority of the study (Table 28 and Figure 27). The CMR and KF results for females are remarkably similar and both indicate a generally increasing trend in female survival (Figures 14 and 27). The range of annual values from the KF analysis started with 0.77, dropped to a low of 0.60 and then ended at 0.826 while the CMR results trended from 0.73 to 0.82 (Figures 14 and 27). Although the KF data for males was for a shorter time period than the CMR dataset, the last 5 years show a similar pattern to that of the CMR data (Figures 11 and 27). In this case the male KF trend starts at a high estimate of 1.0 and ends at 0.63 but hits a low of 0.39 while the CMR trend begins at 0.67 and ends at 0.46 (Figures 11 and 27). In either case males have shown a substantial decline in survival especially during the last 3 years.

#### Mark recapture monitoring – Females Apparent Survival with Habitat Covariates

Forty four female fishers of the 73 females used in the CMR analysis were included in both the known fate and CMR datasets. Thirty six (82%) had 100% of their 95% fixed kernel home range fall within the 3000 m buffer used to calculate habitat covariates for the CMR analysis. On average, 98% of fixed kernel home ranges were contained within the animal's associated 3000m buffer. Therefore, as to be expected, the 3000m buffers were not 100% representative of the individual's home range and surrounding landscape. The CMR analysis with habitat covariates resulted in a number of competing models with various forms of only a few variables much like the KF analysis (Table 29). Unlike the KF analysis however, none of the competing models included more than a single habitat covariate complicating interpretation of the results (Table 29). The top model included a negative effect on apparent survival with increasing percent cover of the stem exclusion strata type (SX) within the landscape scale buffer

(3000 m) (Table 29 and Figures 28 and 29). The second model included a negative effect of increasing total road density (TotRds) also at the landscape scale (Table 29 and Figures 28 and 29). The third and fourth models included SX and TotRds at a smaller home range scale (1900 m buffer) respectively (Table 29). The fifth model did not include any habitat covariates while the sixth model included a positive effect of an increase of mature and older forest (MOF) at the landscape scale (Table 29 and Figures 28 and 29).

## **Discussion**

Bobcat home range and core area sizes that we found in our study were comparatively large in relation to other studies throughout the United States (Ferguson et al. 2009), also suggesting lower densities than in other areas where bobcats occur. Though we did not find differences in habitat use between core areas and 95% fixed kernel home range size, we attribute this to our small sample size. Other studies have found bobcat home ranges to be comprised of more forest habitat than that found in surrounding areas (Tucker et al. 2008) or more lowland forest and wetlands and less upland forest and open fields than in surrounding areas (Preuss and Gehring 2007).

Very few studies have investigated bobcat habitat use where coniferous or mixed-coniferous forests are the dominant habitat type (but see Witmer and deCalesta 1986). However, bobcat habitat-use studies in regions with similar dominant habitat types show some similarities, but many differences to our study (Litvaitis and Harrison 1989, Chamberlain et al. 2003, Pruess and Gehring 2007, Tucker et al. 2008). We observed 1.5 times as many used locations in brush habitats than unused random locations. Results from another study in Vermont were similar in that bobcats more frequently used brush or scrub/shrub habitat than in less-frequently used areas of their home ranges (Donovan et al. 2011). However, in that study and in others (Chamberlain et al. 2003, Preuss and Gehring 2008), field or open habitats were selected against. Contrastingly, we found that 3.5 times as many bobcat locations occurred in open habitats than random locations. The only other study in which bobcats showed preference of open habitats was in agricultural areas of Mississippi (Conner and Leopold 1993). Bobcats in other studies also selected forested habitats over other types (Chamberlain et al. 2003, Preuss and Gehring 2008, Tucker et al. 2008,

Donovan et al. 2011), but in this study, forested habitats were selected against. Of most studies on bobcat habitat selection, habitat conditions in the study by Litvaitis and Harrison (1989) in Maine are likely most similar to that found in our study area. Both in that study as well as this study, bobcats were located more frequently in hardwood forest (in our study area, true-oak woodland) than in random locations.

The few similarities and many differences between bobcat habitat use observed in our study and that observed in other studies are interesting, but as yet, unexplained. Differences may stem from whether the studies occur in areas of bobcat exploitation, distribution of prey abundance and diversity, and possibly dissimilar competitor densities. Neale and Sacks (2001) found slight avoidance by bobcats of coyotes (*Canis latrans*) during coyote breeding seasons and bobcats avoided coyote core areas in south-central Florida (Thornton et al. 2004) which may manifest as differences in use-frequency of certain habitat types. Anecdotal records of coyotes throughout our study area are infrequent and suggest low population density (J.M. Higley, personal communication) which could in turn promote more frequent use by bobcats of typical coyote preferred habitat (open areas, Person and Hirth 1991, or recent clear-cuts, Witmer and deCalesta 1986).

Predation by bobcats is the leading cause of mortality for female fishers throughout California (Wengert et al., unpublished data), though very little is known about the spatial or competitive relationships between these species. Researchers in Wisconsin investigated the effects of a translocated fisher population on the resident bobcat population with the expectation that fishers would have a negative impact on bobcat reproductive rates, kitten and adult survival, body condition, and population density due to resource competition (Gilbert 2000). They found that in bobcat-inhabited areas to which fishers were translocated and maintained high densities, bobcat kitten survival and population growth were lower, suggesting some level of competition between the species and possibly intraguild predation by fishers on bobcat kittens (Gilbert 2000). We have no evidence that fishers prey on bobcat kittens at our study area, but do know that bobcats have killed at least eight adult female fishers (Wengert et al., unpublished data) and likely several more (Higley and Matthews 2007). Unfortunately, there is no

information from the Wisconsin study or any others regarding the shared habitat use of bobcats and fishers or a description of risky habitat heightening chance of encounter between them.

It is well-understood that habitat structure affects the frequency of encounters between intraguild predators and their intraguild prey (Janssen et al. 2007). Among the many routes by which habitat structure might influence intraguild predation, two are particularly relevant at our study area. First, it is often deduced that vegetation or structural elements in forests provide escape cover or concealment for prey, even when predator and prey are in close proximity (Litvaitis et al. 1985, Godbout and Ouellet 2010). Alternatively, vegetation structure may hinder escape if prey rely on visually detecting predators early enough to enable a quick retreat to safe areas, such as underground burrows (Schooley et al. 1996, Thompson and Gese 2007). Second, intraguild prey may simply avoid areas or habitats used frequently by intraguild predators for hunting or traveling (Sergio et al. 2007, Thompson and Gese 2007). When individuals do use these high-risk habitats, probability of encounter and subsequent attack and predation is augmented (Hebblewhite et al. 2005, Kunkel and Pletscher 2000).

We found that habitat structure and anthropogenic features, such as roads and to a certain extent habitat edge, influenced the risk of interaction between bobcats and fishers. Encounters were more likely between bobcats and fishers in areas with greater density of roads and habitat edges. Countless studies have investigated the heightened predation rates on nesting birds at habitat edges (Hartley and Hunter 1998) and frequent use of linear features by predators is common (James and Stuart-Smith 2000, Frey and Conover 2006). Bobcats in our study area frequently use roads, both drivable and overgrown, to travel among high-quality foraging patches (G.M. Wengert, unpublished data). It is interesting that drivable road density, but not nondrivable road density, was important in our best models. Other studies have identified areas with higher road density less likely to be inhabited by bobcats.

The likelihood of a bobcat and a fisher encountering each other depends on two probabilities: the likelihood of fishers occurring where bobcats occur and vice-versa. We found that fishers were more at risk in areas with a smaller proportion of habitat typical for fishers in our study area (older forest with dense canopy, Zielinski et al. 2012), but more typical for bobcats in our study area (G.M. Wengert,

unpublished data). This result suggests that fishers are at risk when they use less commonly used habitats for fishers, rather than when bobcats venture into typical fisher habitat.

Older, mature forest is typically characterized by structure, and in the mixed coniferous forests of northwestern California, this characteristic stems from downed woody debris, tree malformations, snags, and large, highly structured individual trees (Franklin et al. 1981). We found that higher proportions of mature, older forest surrounding fisher locations decreased the odds of encounters with bobcats, consistent with Janssen et al. (2007) findings that habitat structure diminishes impacts to intraguild prey, in this case, fishers. At the same time, greater proportions of young, multistoried forest near fisher locations decreased the odds of fisher-bobcat interactions in our study. This finding is not surprising because young, multistoried Douglas-fir forests also are characteristically structured in that they are comprised of multiple canopy layers, openings created by tree mortality, varying levels of shrub understory, and patches of ground cover. These attributes likely provide cover from predation for forest species.

Although the rate of predation declined during the second half of this study, predation remains a substantial percentage of the total cause of mortality especially for female fishers. We attribute the apparent increase in female survival rate primarily to the reduction in rate of predation. With this reduction in predation the average age at time of death has increased as has the percentage of animals dying from disease. In addition, the mean age of the female population has generally trended upward since the beginning of the study which, coupled with the apparent increase in females, should put the population in a good position to increase. However, with the apparent decline in the male portion of the population and decrease in average male age, there may come a time in the near future where receptive females are not able to breed successfully. Although the total number of male mortalities recorded was low (17) it was concerning that 29.4% (5 of 17) had died as a direct result of anticoagulant rodenticide toxicosis (AR). This is even more alarming when factoring in the high overall exposure rates of fisher to AR (Gabriel et al. 2012) and that several of the fishers with unknown or undetermined causes of death might have been AR related given the fact that the animals had been exposed to more than one toxicant.

In addition, all of the confirmed AR cases occurred from 2010 until the end of the study indicating that the problem may be growing in severity.

We have not confirmed any female direct mortality AR cases, however, many females have tested positive for AR's and it is certainly conceivable that at least some of the predation incidents were the result of predators taking advantage of weakened or disoriented females suffering from the effects of toxicants. Most of the females killed by predators were at least partially consumed and few have been part of the sample of animals tested for rodenticides because their livers were not available. The higher rates of mortality occurring during May and June throughout this study for both males and females also raises the question of whether AR have played a bigger role in female mortality than has been documented thus far. Clearly the higher mortality of males during May and June is directly tied to rodenticides which are placed at illegal marijuana grow sites presumably in late April or early May as the growing season begins. All 5 of the confirmed AR mortalities have occurred in May (4) and June (1) as well as the suspicious unknown case (May). Six of 20 suspected or confirmed female predations have occurred in May, 2 in April and 2 in June. We have speculated that the increased stress of nursing and providing for kits potentially increases the risk of predation. Females may be less observant when more hungry or desperate for prey or while moving kits making them easier prey for bobcats. Alternatively, bobcats might key in on fishers specifically in spring for some unknown reason. On 8 May 2007 two female carcasses were recovered and later confirmed as killed and consumed by bobcats. Only one however, was believed to be denning at the time while the other had apparently failed in her attempt to den early to mid-April.

The decrease in the rate of female predation may be due to a decrease in bobcat density over the course of the study. Since beginning our efforts to capture and collar bobcats it has been very difficult to capture them and all 3 females and 1 male died while we were monitoring them. During the period of March 2012 to February 2013 we failed to capture a single bobcat after over 2000 trap nights. One of the 4 bobcat (F-04) mortalities was tested for AR and was positive. No liver tissue was available from any of the others. If bobcat numbers have declined it would potentially explain the decrease in predation and the



increase in female survival and population given that predation is the major cause of predation and bobcats are by far the number one predator of females. It is possible that fisher populations may respond to changes in their predator's populations.

The KF and CMR analysis have both shown a disturbing trend in male survival. In addition, the annual population estimates and male only lambda estimates have indicated a declining male population. We believe the primary reason for these declines has been AR poisoning associated with illegal marijuana growing. We believe that male fishers are at higher risk of encountering toxicants because they have much larger home ranges than females.

We have documentation of 10 large scale (greater than 5000 plants) trespass grow sites within the Hoopa Valley Indian Reservation from 2007-2012. We have visited 6 of the 10 sites and found evidence of the use of AR's at all 6. Using the mean maximum distance moved data for male and female fishers at Hoopa we have attempted to map the zone of potential impact to fishers from these grow sites (Figures 31 and 32). These sites represent only large sites that have been found by law enforcement and it is likely that there are several, to many others that have gone undetected. In addition, there are numerous small scale "local" grow sites which have not been mapped. The small scale sites may also use AR's and other toxicants but we have no data for such sites. However, none of the males that have died from AR have overlapped any of the large scale grow sites that we have mapped, therefore they are likely encountering the toxicants at undiscovered sites either large or small.

The KF analysis of all the years of female data indicated declining survival for the first 3 years and then a stable yet much higher survival rate for the last 5 years. The CMR analysis indicated a gradual increase in annual apparent survival with remarkably similar estimates of survival to that of the KF analysis for the last 5 years. Overall the CMR estimates of apparent survival and the direction of trends for males and females agree well with the KF estimates and it appears that CMR has very good potential for monitoring long term trends for fishers at Hoopa.

Both the KF and CMR female survival analysis with habitat covariates indicated similar relationships of several habitat variables included in competitive models. On the KF analysis, a negative

effect of density of drivable roads within core use areas was included in all of the competitive models while a negative impact of total road density was included in one of the top competitive CMR models at the landscape scale. Road density apparently negatively impacts female fisher survival. This makes intuitive sense given that they are highly susceptible to predation from bobcats and bobcats show strong selection for drivable roads (Tables 6 and 7). In addition, roads provide human access to fisher habitat where they may negatively influence fisher survival in several ways including placement of toxicants in the environment, habitat alterations, and free ranging dogs. Also included in all of the top KF models was a positive effect of increasing percent cover of open strata. This relationship is not intuitive and seems counter to what we expect except that the range of values of percent open within female home ranges is narrow and generally very low. In fact it appears that female fishers show avoidance of open strata at the home range scale (unpub. data). Therefore, the inclusion of a small amount of open strata within the home range may be beneficial in providing a broader diversity of prey or perhaps higher prey density. The CMR analysis did not include a similar effect of open strata within any of the competitive models.

The last 2 variables of importance within the KF and CMR analysis were percent cover of stem exclusion (SX) and mature and older forest (MOF) strata having negative and positive effects respectively for both analyses. Stem exclusion strata include stands that had been completely replaced within the last 30-60 years, mostly due to intensive clear cut logging. These stands often have a large amount of large down wood but nearly no large standing structures and they have very dense canopies of even age trees allowing little sunlight to reach the forest floor (Appendix A). They produce nearly no hard mast (cones or acorns) because the trees are at a high level of competition with each other fighting for space and sunlight. Therefore they likely produce little food for potential fisher prey. It therefore, makes biological sense that increasing percent cover of this strata might result in decreasing survival rates. At the landscape scale (CMR analysis) the percent cover of SX strata was included in the top model while it was much further down the list for the home range scale and KF analysis.

Increasing percent cover of MOF strata appears to increase female survival at both the home range (KF analysis) and landscape level (CMR analysis). The KF analysis included MOF within the home range in the second model while MOF was further down the list for the CMR analysis at the landscape level. Overall relative agreement of which variables were important and the direction of influence on survival was encouraging given the different scales represented in the 2 analyses.

## **Recommendations**

Timber management, fuels reduction, and other habitat modifications coupled with climate change continue to threaten the long-term persistence of fisher populations in the Pacific states. Our experience with timber management and fisher conservation on the Hoopa Valley Indian Reservation further illustrate the need for an adaptive management approach where these two interests intersect. Following an adaptive management framework, we present the following recommendations under the subheadings of 1) Management Recommendations and 2) Research Needs.

### Management Recommendations

Our management recommendations address fisher conservation at the landscape, stand, and individual structure spatial scales. Landscape scale refers to an area large enough for multiple female home ranges. The size of landscape scale areas will vary from region to region and within regions between vegetative communities, based on varying female home range sizes due to differences in resource availability. For Hoopa and the immediate region, an area of 650 hectares could be used to represent annual female home ranges while 750 hectares would represent lifetime home ranges. Therefore, fisher management should be focused on blocks of potential habitat of 20 or more female home ranges (approximately 13,000 hectares at Hoopa). Land managers that have substantially less area to work with but who are adjacent to larger blocks of potential fisher habitat can still contribute to fisher conservation through activities focused at the level of the timber stand and/or individual tree or other structural elements.

- Retain and/or recruit large diameter trees (hardwoods >20 inches and conifers >30 inches) with deformities and cavities.
  - It is much easier and more immediate to retain large existing trees than to grow them from seed or stump sprouts. The careful selection of leave trees, preferably in groups, to retain post logging and site prep, would be beneficial. Often the best potential current or future wildlife trees will have deformities, defects and heart rot fungi, which make them less desirable for commercial harvest. Retaining trees in groups helps to reduce loss from wind throw and may allow retention of a diversity of species, size and age classes of trees.
- Retain or recruit large diameter conifer snags
  - Fishers use large diameter conifer snags for resting and denning and many potential prey species use them as well. It is often difficult to save snags within timber harvest units due to safety concerns but when feasible it should be done. In addition, if significant snag patches exist, consider buffering them outside of timber sale units to ensure their protection.
- Retain or recruit large down wood
  - Although fishers in Hoopa do not use logs for resting or denning on a regular basis, they do use them occasionally. Large logs may actually be more important for prey, foraging, travel and escape cover. They are certainly an important part of a healthy forest and are extremely difficult to replace in stands managed under regeneration silviculture. Protect existing logs and leave standing conifers to grow and eventually fall to recruit new wood.
- Maintain a natural mix of tree species for each site and retain or recruit large diameter trees
  - Allow for the retention of hardwoods as single trees or patches when implementing stand improvement activities for timber production. Do not remove or spray them all.
- Encourage or at least tolerate natural ecological processes

- Foresters and silviculturists strive to remove fungal infection, insects and disease from the forest to protect developing stands. Endemic representatives of these species and processes are extremely important for the ecological health of the forest. Most cavities used by fishers begin with a heart rot fungal infection.
- If practical, employ uneven aged management systems using thinning, single tree or small group selection
- If using even aged management systems, attempt to reduce fragmentation over large areas
  - The practice of clear cutting in patches of 20-40 acres at a time leads to a mosaic of early seral stages mixed with maturing forest habitat of various ages generally up to the rotation age. These landscape patterns do not mimic any natural disturbance regimes and may ensure that huge areas are unsuitable for fishers, simply because they are fit for a host of fisher predators which do well in fragmented landscapes. Increasing the size of regeneration units while at the same time retaining structural elements in groups and stream zones would eventually reduce fragmentation. Units or aggregates of units of 100-500 hectares or more may better represent historic disturbance patterns and result in better potential fisher habitat in the future so long as the structural elements are retained.
- Retain or develop large areas of mature forest
  - It is clear that large tracts of mature and old growth forests provide good habitat for fishers and appear to increase survival rates. Retaining and protecting these areas from catastrophic fire would benefit fishers. In some instances protection of these areas may include fuel reduction projects since the exclusion of fire for extended periods has rendered them vulnerable to fire. However, constructing new roads to access such stands would likely be detrimental to fishers in both the short and long run.
- Protect existing large scale areas of young and mature closed canopy forests from catastrophic wildfire

- Fishers at Hoopa often are found resting and denning in mature stands that have thick understory vegetation and abundant ladder fuels. It may be that fishers select for this type of condition, therefore fuel reduction projects should be implemented with caution and should strive to retain a mixture of conditions across the landscape and avoid creating ‘park-like’ conditions everywhere.
- Stands that were clear cut and have achieved stem exclusion stage appear to be of low value or possibly detrimental to fisher survival. The reason is not known but we speculate that these stands are low to very low on potential prey because there are few if any mast producing trees. In addition, these stands were intensively cut, often with tractors even on steep slopes, therefore there are often many skid trails and non-drivable roads that may increase risk of predation. Creating small openings and conducting variable density thinning projects (either commercial or non-commercial) may speed up the recovery of these sterile stands by allowing some trees to express dominance and begin to produce mast and by allowing for sunlight to reach the forest floor to stimulate understory vegetation growth both of which may contribute to an increase of potential prey.

#### Research Needs

- Establish long term demographic monitoring projects within areas supporting extant populations of West Coast fishers with the goal of describing fisher habitat fitness potential in key vegetative communities
- Continue to investigate causes of fisher mortality across the extant western populations
- Where predation is the major source of mortality (such as Hoopa), continue to investigate the ecological relationship between fishers and their main predators
  - Simultaneously monitor populations of fishers and their main predators along with habitat use and selection of all species at the same time

- Further investigate the relationship between landscape habitat patterns and fisher predator populations
  - Which landscape patterns result in the presence of both fisher and their predators occupying the same areas. Is predation risk associated with identifiable habitat conditions? If so, are these conditions the result of management activities?
- Investigate relationship between fisher prey populations, prey habitat and fisher home range establishment, home range size and population density
- Investigate competition for prey between fisher and their main predators and relationship to prey populations; link to predation rates
- In areas with a significant component of tanoak, develop a solid baseline of fisher population demographic parameters such as home range size, density, survival, reproduction and quantify habitat conditions including extent of coverage of tanoak, estimates of mast production and cavity availability. All of these things may be severely changed in the next 25-100 years as climate change advances and the spread of sudden oak death continues.
- Investigate the relationship between marijuana growing and fisher population demography. Particularly outdoor growing on public and tribal lands but also greenhouse and outdoor growing on private land adjacent to or within fisher habitat.

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**Table 1. Descriptions of habitat variables included in analyses of bobcat (*Lynx rufus*) habitat selection and predation risk of fishers (*Pekania pennanti*) by bobcats.**

Variable	Description
STRATA	Categorical variable with seven habitat types below
MOF	Mature and Older Forest
YFM	Young Multistoried Forest
YCCF	Young Closed-canopy Forest
TOW	True Oak Woodland
BRUSH	Dense Brush
OPSHRB	Open canopy, low to moderately dense shrub/pole tree cover
OPEN	Prairie, landslide, urban industrial
MAN	Lumps CABLE and TRACTOR (below) to represent all logged areas
CABLE	Managed Forest Logged with Yarder
TRACTOR	Logged with Tractors, makes a network of skid roads of varying density
NONFOR	Lumps BRUSH, OPEN and OPSHRB together to represent non-forest cover
FOR	Lumps MOF, YFM, YCCF and TOW together to represent forest cover
EDGE	Any edge between two habitat strata types
HRDEDGE	Any edge between FOR and NONFOR
ROAD	Total Road density
DRVROAD	Drivable Road density
NODRVROAD	Non-drivable (brushed over) road density

**Table 2 Description of habitat variables used for known fate and capture-mark-recapture apparent survival analysis with habitat covariates, Hoopa fisher study area, Humboldt County, CA, 2004-05 to 2012-13.**

Variables		Description	Survival Modeling Expectations and Justifications
<b>Forest Composition Variables</b>			
Percent Mature and Old Forest	P_MOF	% home range in MOF	Positive: Fishers have often been associated with late seral forests, and clearly benefit from structural elements found within them.
Percent Young Closed Canopy Forest	P_YCCFs	% home range in YCCFs	Positive or Neutral: YCCFs stands are young growth with significant residual old, large trees, Fishers at Hoopa den and rest in these stands and we expect that these stands would benefit survival in the absence of late seral habitat
Percent Stem Exclusion	P_SX	% home range in SX	Neutral: Stem exclusion stands should provide adequate dispersal and foraging cover. They often have low productivity and lack structural elements making them prey desserts and not providing much structure for resting or denning. Not expected to benefit bobcats or Mt. Lions
Percent True Oak Woodland	P_TOW	% home range in TOW	Neutral or Negative: True oak woodlands may provide resting and denning sites but large stands of TOW stands are without much overhead cover during the leaf off period, they also tend to be slightly more open canopy and generally have a relatively open understory. They may provide good habitat for fisher predators.
Percent Dense Brush with low Tree Cover	P_MCOV	% home range in MCOV	Neutral +/-: MOCOV stands may provide fisher benefits as the often have high levels of prey (woodrats) but they also may be attractive to fisher predators
Percent Open	P_OPEN	% home range in OPEN	Negative: Open areas tend to be avoided by fishers and large amounts of open habitat would be considered highly negative, however, open areas that are the result of disturbance of otherwise forested sites may have some benefits by providing edges and diversity and increasing prey diversity and availability. They are also however, attractive areas for bobcats, coyotes and Mt. Lions

Percent Complex forest	P_CF	% home range in MOF and YCCFs	Positive: Closed canopy Complex Forest should benefit fishers. They should provide all aspects of fishers needs for den, rest and foraging.
Percent Forested Patches	P_FOR	% home range in MOF, YCCFs, and SX	Neutral to Positive: Depending on the make up of the forest types contributing to this variable it could be beneficial or neutral to slightly negative. High amounts of SX and low MOF/YCCFs might be negative while the reverse should be beneficial. High variation in the make up of this category will likley render it of low value in the modeling effort unless fishers truly benefit from any closed canopy forest regardless of seral stage
Percent Open Patches	P_OPEN	% home range in TOW, MCOV, and OPEN	Neutral: The Non-closed canopy forest strata can be made up of several strata, each with different potential affects to fishers, therefore this variable will likely be of little use in modeling, also should be directly related to the FOR variable and not used together
Interior Area Mature and Old Forest	CP_MOF	% home range comprised of interior area MOF (using 'interior' so as to not confuse 'core' home range with Fragstats use of 'core'). Use 50m edge depth.	Positive: High levels of Interior MOF should benefit fishers as it would indicate that there was high total amounts and that stands would be larger, creating large blocks of habitat that provide all the fishers needs while being less likely to attact predators.
Interior Area Young Closed Canopy Forest	CP_YCCFs	% home range comprised of interior area YCCFs	Positive to Neutral: Asuming that YCCFs is a benefit to fishers, larger contiguous blocks of it would be better, however, the more of YCCFs the less of MOF would likely be available. A variable that combined MOF and YCCFs (i.e. Interior CF) might be a good variable to include.
Interior Area Stem Exclusion	CP_SX	% home range comprised of interior area SX	Negative to Neutral: Too much SX would result in lower amounts of MOF and YCCFs
Interior Area True Oak Woodland	CP_TOW	% home range comprised of interior area TOW	Negative: Large amounts of TOW would likely be detrimental due to increase risk of predation
Interior Area Brush	CP_MCOV	% home range comprised of interior area MCOV	Negative: Large amounts of MCOV would likely be detrimental due to increase risk of predation

Interior Area Open	CP_OPEN	% home range comprised of interior area OP	Negative: Large amounts of OPEN would likely be detrimental due to increase risk of predation, however, the total range of P_OPEN and CP_OPEN is vary narrow and at the low end of the scale. Therefore, it might come out as beneficial due to increase in prey
<b>Forest Configuration Variables - Patch Scale</b>			
Mature and Old Forest edge density	ED_MOF	Density (m/km2) of MOF edges	Negative to Neutral: The higher the edge density the more fragmented the MOF would be. This one is complicated however, because some Hrs might have low ED_MOF because they have very little MOF while others have highly fragmented MOF, probably best used in combination with PMOF or CPMOF if they are not too highly correlated. Also complicated by the lack of differentiation between edge types, ED where edges are between MOF and YCCFs or SX may not really have edge effects for fishers at all
Young Closed Canopy Forest edge density	ED_YCCFs	Density (m/km2) of YCCFs edges	Negative to Neutral: The higher the edge density the more fragmented the YCCFs would be. This one is complicated however, because some Hrs might have low ED_MOF because they have very little MOF while others have highly fragmented MOF, probably best used i
Stem Exclusion edge density	ED_SX	Density (m/km2) of SX edges	Neutral
True Oak Woodland edge density	ED_TOW	Density (m/km2) of TOW edges	Negative
Brush edge density	ED_MCOV	Density (m/km2) of MCOV edges	Neutral, higher risk of predation but higher prey availability
Open edge density	ED_OPEN	Density (m/km2) of OPEN edges	Negative due to risk of predation
Mature and older forest fragmentation	CLP_MOF	Clumpiness index of mature forest, indicating degree to which MOF forest is fragmented into smaller patches	Higher clumpiness should be beneficial since it should indicate larger patch sizes closer together



Young closed canopy forest fragmentation	CLP_YCCFs	Clumpiness index of complex forest, indicating degree to which YCCFs is fragmented into smaller patches	Higher clumpiness should be beneficial since it should indicate larger patch sizes closer together
Stem exclusion fragmentation	CLP_SX	Clumpiness index of forested patches, indicating degree to which SX forest is fragmented into smaller patches	
True oak woodland fragmentation	CLP_TOW	Clumpiness index of forested patches, indicating degree to which TOW forest is fragmented into smaller patches	
Brush fragmentation	CLP_MCOV	Clumpiness index of forested patches, indicating degree to which MCOV forest is fragmented into smaller patches	
Open patches fragmentation	CLP_OPEN	Clumpiness index of open patches, indicating degree to which OPEN patches are fragmented into smaller patches	
Mature and older forest isolation	PRX_MOF	Proximity index among MOF forest patches, indicating the mean distance between MOF patches weighted proportional to their area	
Young closed canopy isolation	PRX_YCCFs	Proximity index among YCCFs patches, indicating the mean distance between YCCFs patches weighted proportional to their area	
Stem exclusion isolation	PRX_SX	Proximity index among SX patches, indicating the mean distance between SX patches weighted proportional to their area	

True oak woodland isolation	PRX_TOW	Proximity index among TOW patches, indicating the mean distance between TOW patches weighted proportional to their area
Brush isolation	PRX_MCOV	Proximity index among MCOV patches, indicating the mean distance between MCOV patches weighted proportional to their area
Open patches isolation	PRX_OPEN	Proximity index among OPEN patches, indicating the mean distance between OPEN patches weighted proportional to their area

#### **Forest Configuration Variables - Landscape Scale**

Patch edge density	ED	Density (m/km <sup>2</sup> ) of edge of all patch types	Negative: High ED density would likely relate to highly fragmented areas which should favor larger predators
Total edge contrast index	TECI	Quantifies edge contrast as a percentage of the maximum possible for the landscape as a whole	
Landscape fragmentation	CONTAG	Tendency of cells of similar class type to be aggregated, indicating overall landscape clumpiness	Positive: when associated with higher levels of MOF and/or YCCF
Granularity	SIDI	Compound measure of landscape diversity based on the richness and evenness of patch types (Weir and Corbould 2010 used no. of stands/km <sup>2</sup> in home range)	

#### **Linear Feature Variables**

Total Road density	TotRd	Density of all roads (m/km <sup>2</sup> ) in each home range	Negative: Would expect higher road density to decrease survival by potentially increasing predation risk, indirectly might be correlated to habitat quality with higher rd density having more managed lands and increased human access
Drivable Road Density	DRd	Density of Drivable roads (m/km <sup>2</sup> ) in each home range	Negative: Would expect higher drivable road density to decrease survival by potentially increasing predation risk, indirectly might be correlated to habitat quality with higher rd density having more managed lands and increased human access
Non-Drivable Road Density	NDRd	Density of Non-Drivable roads (m/km <sup>2</sup> ) in each home range	Negative: Would expect higher non-drivable road density to decrease survival by potentially increasing predation risk, indirectly might be correlated to habitat quality with higher rd density having more managed lands
Creek density	CRK	Density of creeks and rivers (m/km <sup>2</sup> ) in each home range	Neutral or positive: Although creeks are linear features that may be exploited by predators such as bobcats, I would expect that the productivity of the riparian zone habitat associated with creeks would keep this a neutral or positive affect.

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**Table 3 Bobcat (*Lynx rufus*) 95% fixed kernel home ranges (sq. km), core area percent of home range, and core area (sq. km) at Hoopa Valley Indian Reservation, 2010 – 2012.**

Bobcat	95 %Fixed Kernal	Core Area %	Core Area
F02	11.1	60	3.7
F03	18.3	70	4.1
F04	13.7	60	3.9
M01	92.0	60	23.4
M02	13.7	60	4.6
M03	45.7	60	15.4
M04	79.1	60	25.3

**Table 4. Table 4. Average and standard errors of proportions of 95% fixed kernel and core home ranges for seven bobcats (*Lynx rufus*) consisting of the different habitat strata and overall study area composition of habitat strata at Hoopa Valley Indian Reservation, February 6, 2011 and October 31, 2012.**

Parameter	95% Fixed Kernel		Core Fixed Kernel		Study Area
	Mean	SE	Mean	SE	
MOF	0.242	0.044	0.196	0.050	0.254
YFM	0.276	0.037	0.273	0.035	0.254
YCCF	0.231	0.030	0.193	0.037	0.223
BRUSH	0.087	0.009	0.115	0.027	0.083
OPSHRB	0.076	0.012	0.064	0.018	0.109
OPEN	0.058	0.020	0.110	0.047	0.044
TOW	0.030	0.011	0.049	0.019	0.033

**Table 5. Average proportion of total locations in different habitat strata and averages and standard errors of other habitat variables at “used” locations of GPS-collared bobcats (*Lynx rufus*) and randomly created locations (included as “available” locations in habitat selection analyses) throughout bobcat 95% fixed kernel home ranges at Hoopa Valley Indian Reservation, 2010 – 2012.**

	Used		Available	
	Average proportion or distance (m)	SE	Average proportion or distance (m)	SE
Habitat Strata				
BRUSH	0.140	0.027	0.087	0.009
MOF	0.121	0.032	0.252	0.044
OPSHRB	0.099	0.025	0.080	0.015
YCCF	0.138	0.040	0.226	0.030
OPEN	0.260	0.100	0.059	0.023
TOW	0.048	0.020	0.030	0.012
YFM	0.194	0.044	0.265	0.033
FOR	0.501	0.077	0.774	0.024
NONFOR	0.499	0.077	0.226	0.024
Distance to EDGE (m)	61.29	3.79	67.78	4.70
Distance to HRDEDGE (m)	137.81	18.93	155.71	12.46
Distance to ROAD (m)	105.63	8.64	132.69	5.58
Distance to DRVROAD (m)	173.72	27.52	232.11	25.15
Distance to NODRVROAD (m)	474.72	111.99	400.35	70.86

**Table 6. Model performance statistics of three top models of habitat selection by bobcats (*Lynx rufus*) at Hoopa Valley Indian Reservation, Hoopa, CA, built with location data collected from GPS and VHF collars on seven bobcats between February 6, 2011 and October 31, 2012. STRATA represents a categorical variable consisting of seven habitat types. Other variables include distance to nearest road (ROAD, m), distance to nearest edge between habitat types (EDGE, m), distance to nearest edge between forest and non-forest habitats (HRDEDGE, m), and distance to nearest driveable road (DRVROAD, m). Individual bobcat was included as a random effect in all models tested.**

Model	K	Log-likelihood	AICc	$\Delta AICc$	$w_i$
STRATA + ROAD + EDGE	10	-4561.093	9142.217	0.0000	0.4649
STRATA + ROAD + HRDEDGE	10	-4561.258	9142.548	0.3316	0.3939
STRATA + DRVROAD + HRDEDGE	10	-4562.562	9145.155	2.9377	0.1070

**Table 7. Model-averaged estimates of coefficients ( $\beta$ ), standard errors, odds ratios and results of significance tests for the top model of habitat selection by bobcats (*Lynx rufus*) at Hoopa Valley Indian Reservation, Hoopa, CA, built with location data collected from GPS and VHF collars on seven bobcats between February 6, 2011 and October 31, 2012. Shown are seven habitat categories within the STRATA categorical variable, and distance to nearest road (ROAD, m), distance to nearest edge between any two habitat types (EDGE, m), and distance to nearest edge between forest and non-forest habitats (HRDEDGE, m).**

Parameter	$\beta$	SE	Odds Ratio	Wald Statistic	<i>P</i>
STRATA					
Intercept (BRUSH)	0.6127	0.1365	1.8453	4.489	< 0.001
MOF	-1.0069	0.1036	0.3653	9.723	< 0.001
OPEN	1.0670	0.1280	2.9068	8.338	< 0.001
OPSHRB	-0.3481	0.1091	0.7060	3.191	0.0014
TOW	0.0298	0.1588	1.0303	0.188	0.851
YCCF	-0.9636	0.1160	0.3815	8.303	< 0.001
YFM	-0.8200	0.1025	0.4404	8.002	< 0.001
ROAD	-0.0148	0.0026	0.9853	5.671	< 0.001
EDGE	-0.1285	0.0039	0.9872	3.267	0.0011
HRDEDGE	0.0056	0.0017	1.0056	3.230	0.0012



**Table 8. Means and standard errors of habitat variables comprising regions of overlap between fisher (*Pekania pennanti*) 95% fixed kernels and bobcats (*Lynx rufus*) core areas, and regions of fisher kernels that don't overlap with a bobcat at Hoopa Valley Indian Reservation, between February 6, 2011 and October 31, 2012. Also shown are the results of paired t-tests between habitat composition (%) of the region of a fisher's home range where it overlaps with a bobcat core and the region where it does not overlap with a bobcat core.**

	Overlap Regions		Non-overlap Regions		<i>P</i>
	Mean	SE	Mean	SE	
Habitat Strata					
%MOF	39.11	4.51	34.98	3.79	0.271
%YCCF	18.78	4.60	20.76	3.39	0.565
%YFM	20.36	2.34	26.88	3.38	0.096
%OPSHRB	1.93	0.47	5.04	1.20	0.017
%OPEN	2.79	0.95	1.42	0.53	0.150
%TOW	4.13	1.14	3.05	1.02	0.374
%BRUSH	12.89	4.62	7.88	1.04	0.290
%FOR	82.39	4.32	85.66	1.83	0.505
%NONFOR	17.61	4.32	14.34	1.83	0.505
ROAD density (km/km <sup>2</sup> )	2.53	0.27	2.97	0.25	0.326
DRVROAD density (km/km <sup>2</sup> )	2.15	0.29	1.80	0.18	0.369
NODRVROAD density (km/km <sup>2</sup> )	0.38	0.13	1.17	0.16	0.005
EDGE density (km/km <sup>2</sup> )	7.48	0.26	7.82	0.85	0.743
HRDEDGE density (km/km <sup>2</sup> )	2.68	0.38	2.76	0.45	0.871

**Table 9. . Model performance statistics of three top models of kernel overlap of bobcats (*Lynx rufus*) and fishers (*Pekania pennanti*) at Hoopa Valley Indian Reservation, Hoopa, CA, between February 6, 2011 and October 31, 2012. Individual fisher was included as a random effect in all models tested.**

Model	K	Log-likelihood	AICc	$\Delta$ AICc	$w_i$
NODRVROAD + YFM + OPEN	5	-8.5340	29.5681	0.0000	0.3639
NODRVROAD + OPEN	4	-10.2292	30.0585	0.4904	0.2848
NODRVROAD + YFM + OPEN + MOF	6	-8.3314	32.3149	2.7468	0.0922

**Table 10. Model-averaged estimates of coefficients ( $\beta$ ), standard errors, odds ratios and results of significance tests for the top model of kernel overlap of bobcats (*Lynx rufus*) and fishers (*Pekania pennanti*) at Hoopa Valley Indian Reservation, Hoopa, CA, between February 6, 2011 and October 31, 2012.**

Parameter	$\beta$	SE	Odds Ratio	Wald Statistic	<i>P</i>
Intercept	3.9261	2.7141	50.7102	1.447	0.1480
NODRVROAD	-5.0732	1.9413	0.0063	2.613	0.0090
YFM	-0.1256	0.0786	0.8819	1.599	0.1098
OPEN	0.7366	0.3245	2.0889	2.270	0.0232

**Table 11. Sample sizes (number of individuals) of 4 known fate datasets used to estimate survival of fishers (*Pekania pennanti*) within the Hoopa fisher study area, Humboldt County, CA. 2005-06 to 2012-13.**

Data Set	Duration		Number of Individuals		Total Records	Groups
	Year Begin	Year End	Males	Females		
Both Sexes	2008-09	2012-13	34	39	181	10, Yrs/sex
Males Only	2008-09	2012-13	34	0	75	5, Yrs
Females Only	2005-06	2012-13	0	62	183	8, Yrs
Females Only w/Habitat	2005-06	2012-13	0	47	47	1

**Table 12 Descriptions of 4 known fate datasets used to estimate survival of fishers (*Pekania pennanti*) within the Hoopa fisher study area including duration, number of individuals, number of occasions (months), number of mortalities and number censored, Humboldt County, CA. 2005-06 to 2012-13.**

Datasets:	Both Sexes	Males Only	Females Only	Females Only w/Habitat
Duration	5 Yrs	5 Yrs	8 Yrs	8 Yrs
Individuals	73	34	62	41
Numbers of Occasions (months)				
Min.	1	2	1	2
Max.	60	50	82	77
Mean	19.8	15.2	22.9	31.6
Total	1449	516	1421	1295
Mortalities	29	14	30	26
Censored-Lost	21	11	12	8
Censored-end	23	9	20	7

**Table 13. Causes of mortality of male and female fishers (*Pekania pennantii*) on the Hoopa fisher study area, Humboldt County, CA, 2005-2013.**

Cause of Mortality	Male			Female		
	Confirmed	Suspected	Total	Confirmed	Suspected	Total
Predation	3	2	5	12	8	20
Disease	2	1	3	7	0	7
Toxicosis	5	0	5	0	0	0
Research	1	0	1	1	0	1
Unknown	2	1	3	0	3	3

**Table 14. Total percent of mortalities by cause for male and female fishers (*Pekania pennanti*) for the period 2005-2013 and percent by cause for females during the periods 2005-2008 and 2009-2013 on the Hoopa fisher study area, Humboldt County, CA, 2005-2013.**

Cause of Mortality	Total %	Total %	2005-08	2009-12	2005-08	2009-12
	Males	Females				
Predation	29.4%	64.5%	14	6	73.7%	50.0%
Disease	17.6%	22.6%	2	5	10.5%	41.7%
Toxicosis	29.4%	0.0%	0	0	0.0%	0.0%
Research	5.9%	3.2%	1	0	5.3%	0.0%
Unknown	17.6%	9.7%	2	1	10.5%	8.3%

**Table 15 Model results of fisher (*Pekania pennanti*) survival (including males and females) using 5 years of known fate data (2008-09 to 2012-13) Hoopa Valley Indian Reservation, Humboldt County, CA.**

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Num. Par	Deviance
{S(s+M_Yrs12+MayJune)}	270.210	0.000	0.369	1.000	4	262.182
{S(s+M-AnT+M-TT+MayJune)}	270.546	0.336	0.312	0.845	5	260.504
{S(s+M-AnT+M-TT+F-AnT+F-TT+MayJune)}	272.188	1.979	0.137	0.372	7	258.111
{S(M_Yrs12+MayJune)}	274.985	4.775	0.034	0.092	3	268.968
{S(s+M_Yrs12)}	275.214	5.005	0.030	0.082	3	269.198
{S(s+M-AnT+MayJune)}	275.255	5.046	0.030	0.080	4	267.228
{S(AnT+TT+MayJune)}	276.077	5.867	0.020	0.053	4	268.049
{S(s+AnT+TT+MayJune)}	276.448	6.238	0.016	0.044	5	266.406
{S(Yrs12+MayJune)}	277.739	7.529	0.009	0.023	3	271.722
{S(s+Yrs12+MayJune)}	278.102	7.892	0.007	0.019	4	270.074
{S(AnT+MayJune)}	278.126	7.916	0.007	0.019	3	272.109
{S(s+AnT+MayJune)}	278.302	8.093	0.006	0.018	4	270.275
{S(s+AnT+MayJune)}	278.302	8.093	0.006	0.018	4	270.275
{S(sex+Yrs+MayJune)}	278.526	8.317	0.006	0.016	11	256.343
{S(sex+MayJune)}	280.963	10.754	0.002	0.005	3	274.947
{S(MayJune)}	281.003	10.793	0.002	0.005	2	276.995
{S(AnT+TT)}	281.133	10.923	0.002	0.004	3	275.116
{S(Yrs12)}	282.817	12.607	0.001	0.002	2	278.808
{S(s+Yrs12+Grow+NonGrow)}	282.910	12.700	0.001	0.002	5	272.868
{S(MayJune)}	283.011	12.802	0.001	0.002	3	276.995
{S(s+Yrs12)}	283.202	12.993	0.001	0.002	3	277.186
{S(g+Grow_NonGrow)}	283.374	13.164	0.001	0.001	12	259.157
{S(g)}	283.692	13.482	0.000	0.001	10	263.539
{S(s+Yrs12+Breed+NonBreed)}	283.701	13.492	0.000	0.001	5	273.660
{S(g+T)}	284.321	14.112	0.000	0.001	11	262.138
{S(Yrs)}	284.457	14.248	0.000	0.001	5	274.416
{S(g+T+TT)}	286.121	15.912	0.000	0.000	12	261.904
{S(sex)}	286.291	16.081	0.000	0.000	2	282.282
{S(s+Yrs12+Breed+Rear+NonBreed)}	286.326	16.116	0.000	0.000	6	274.268
{S(s+Breed+NonBreed)}	286.516	16.306	0.000	0.000	4	278.488
{S(g+AnT+AnTT)}	287.756	17.547	0.000	0.000	12	263.539
{S(g+t)}	291.338	21.128	0.000	0.000	21	248.690
{Global PIM}	450.743	180.533	0.000	0.000	120	188.875

**Table 16 . Model results of female fisher (*Pekania pennanti*) survival using 8 years of known fate data (2005-06 to 2012-13) Hoopa Valley Indian Reservation, Humboldt County, CA.**

Model	AICc	Delta AICc	AICc Weight s	Model Likelihood	Num. Par	Deviance
{S(Yrs123T+MayJune)}	282.116	0.000	0.380	1.000	3	276.099
{S(Yrs123+MayJune)}	283.491	1.375	0.191	0.503	3	277.474
{S(Yrs123T+Yrs4-8T+MayJune)}	283.961	1.845	0.151	0.398	4	275.933
{S(MayJune)}	285.120	3.004	0.085	0.223	2	281.112
{S(AnT+MayJune)}	285.906	3.790	0.057	0.150	3	279.890
{S(Yrs123T+Yrs4-8+MayJune)}	286.381	4.265	0.045	0.119	7	272.302
{S(AnT+AnTT+MayJune)}	287.748	5.632	0.023	0.060	4	279.720
{S(Yrs123+T)}	288.479	6.363	0.016	0.042	3	282.462
{S(Yrs123+2Seasons)}	289.672	7.556	0.009	0.023	4	281.644
{S(Yrs123+T+TT)}	289.686	7.570	0.009	0.023	4	281.657
{S(AnT+TTMayJune)}	289.762	7.646	0.008	0.022	5	279.720
{S(T)}	290.075	7.959	0.007	0.019	2	286.066
{S(2Seasons)}	291.445	9.329	0.004	0.009	3	285.428
{S(T+TT)}	291.472	9.356	0.004	0.009	3	285.455
{S(Yr+grow+other)}	291.525	9.409	0.003	0.009	10	271.369
{S(Yrs123)}	291.679	9.563	0.003	0.008	2	287.670
{S(3Seasons)}	291.686	9.570	0.003	0.008	4	283.658
{S(.)}	292.840	10.724	0.002	0.005	1	290.837
{S(Yr+T)}	294.617	12.501	0.001	0.002	9	276.489
{S(Yr+T+TT)}	295.781	13.665	0.000	0.001	10	275.625
{S(Yr+2Seasons)}	295.864	13.748	0.000	0.001	10	275.708
{S(Yr+3Seasons)}	296.314	14.198	0.000	0.001	11	274.126
{S(Yr)}	297.315	15.199	0.000	0.001	8	281.213
{S(g+t)}	304.765	22.649	0.000	0.000	19	266.223
		124.67				
{S(g*t)}	406.791	5	0.000	0.000	96	200.725

**Table 17 Model results of male fisher (*Pekania pennanti*) survival using 5 years of known fate data (2008-09 to 2012-13) Hoopa Valley Indian Reservation, Humboldt County, CA.**

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Num. Par	Deviance
{S(Yrs12+MayJune)}	113.62	0.00	0.366	1.000	3	107.57
{S(AnT+TT+MayJune)}	113.63	0.02	0.362	0.991	4	105.56
{S(Yr+MayJune)}	117.43	3.82	0.054	0.148	6	105.27
{S(Yrs12+2Seasons)}	117.75	4.14	0.046	0.126	3	111.71
{S(Yrs12+GrowSeason)}	117.85	4.23	0.044	0.121	3	111.80
{S(AnT+MayJune)}	118.58	4.96	0.031	0.084	3	112.53
{S(Yrs12+T)}	118.87	5.25	0.026	0.072	3	112.82
{S(AnT+TT+mT)}	119.20	5.58	0.022	0.061	4	111.12
{S(Yrs12)}	119.55	5.94	0.019	0.051	2	115.53
{S(Yrs12+T+TT)}	120.47	6.85	0.012	0.033	4	112.39
{S(g+AnT+TT+MayJune)}	121.55	7.94	0.007	0.019	8	105.27
{S(Yr+T)}	122.95	9.33	0.003	0.009	6	110.78
{S(AnT+T)}	123.75	10.13	0.002	0.006	3	117.70
{S(g)}	123.96	10.35	0.002	0.006	5	113.85
{S(Yr+T+TT)}	124.42	10.80	0.002	0.005	7	110.20
{S(g+t)}	127.09	13.47	0.000	0.001	16	94.00
{S(T)}	129.09	15.47	0.000	0.000	2	125.06
{S(T+TT)}	130.73	17.11	0.000	0.000	3	124.68
{S(t)}	133.76	20.15	0.000	0.000	12	109.14
{Global PIM}	215.79	102.18	0.000	0.000	60	79.70
{Global {S(g*t)}}	215.79	102.18	0.000	0.000	60	79.70



**Table 18. Model results of female fisher (*Pekania pennanti*) survival using 8 years of known fate data (2005-06 to 2012-13) with habitat covariates, Hoopa Valley Indian Reservation, Humboldt County, CA.**

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Num. Par	Deviance
{S(cDRd+OPEN)}	245.354	0.000	0.118	1.000	3	239.336
{S(cDRd+OPEN+qMOF)}	245.957	0.602	0.087	0.740	4	237.926
{S(cDRd+OPEN+MOF)}	246.138	0.783	0.080	0.676	4	238.107
{S(cDRd+OPEN+Dist_Urban)}	246.182	0.828	0.078	0.661	4	238.151
{S(cDRd+OPEN+lnMOF)}	246.367	1.013	0.071	0.603	4	238.336
{S(cDRd+OPEN+SX)}	246.498	1.143	0.067	0.565	4	238.467
{S(cDRd+OPEN+TOW)}	246.562	1.208	0.064	0.547	4	238.531
{S(cDRd+OPEN+MCOV)}	246.799	1.444	0.057	0.486	4	238.768
{S(cDRd+OPEN+CONTAG)}	247.178	1.824	0.047	0.402	4	239.147
{S(cDRd+OPEN+cMOF)}	247.241	1.887	0.046	0.389	4	239.210
{S(cDRd+OPEN+PRX_MOF)}	247.336	1.981	0.044	0.371	4	239.305
{S(cDRd+OPEN+HEdge)}	247.339	1.984	0.044	0.371	4	239.308
{S(cDRd+OPEN+CLP_MOF)}	247.348	1.993	0.044	0.369	4	239.317
{S(cDRd+OP+MOF)}	247.566	2.211	0.039	0.331	4	239.535
{S(cDRd)}	248.245	2.891	0.028	0.236	2	244.236
{S(cDRd+MCOV)}	248.446	3.092	0.025	0.213	3	242.427
{S(cDRd+SX)}	249.986	4.632	0.012	0.099	3	243.967
{S(cDRd+MOF)}	250.177	4.823	0.011	0.090	3	244.158
{S(cDRd+MOFint)}	250.215	4.861	0.010	0.088	3	244.197
{S(cDRd+cTractor)}	250.247	4.892	0.010	0.087	3	244.228
{S(OPEN)}	252.932	7.578	0.003	0.023	2	248.923
{S(cTRd_den)}	252.972	7.617	0.003	0.022	2	248.962
{S(lnOPEN)}	253.745	8.391	0.002	0.015	2	249.736
{S(cTractor)}	255.168	9.814	0.001	0.007	2	251.159
{S(FOR)}	255.563	10.208	0.001	0.006	2	251.553
{S(OP95)}	255.563	10.208	0.001	0.006	2	251.553
{S(Tractor)}	255.850	10.496	0.001	0.005	2	251.841
{S(SX)}	256.113	10.758	0.001	0.005	2	252.103
{S(TRd_den)}	256.274	10.919	0.001	0.004	2	252.265
{S(qMOF)}	256.324	10.970	0.000	0.004	2	252.315
{S(cMan)}	256.383	11.029	0.000	0.004	2	252.374
{S(MOF)}	256.506	11.152	0.000	0.004	2	252.497
{S(cMOF)}	256.651	11.297	0.000	0.004	2	252.642
{S(.) PIM}	256.702	11.348	0.000	0.004	1	254.699

**Table 19 Fisher (*Pekania pennanti*) live capture effort and number of animals captured by year on the Hoopa fisher study area, Humboldt County, CA, 2004-05 to 2012-13. (Ages unavailable for 2012-13)**

Year	Trap Sites	Trap Nights	Total Captures	Non-Juvenile		Juvenile		Total Indv.
				M	F	M	F	
2004-05	137	1583	129	16	13	4	1	34
2005-06	136	1735	87	18	13	1	6	38
2006-07	122	2032	112	15	17	9	4	45
2007-08	126	2517	107	16	17	3	5	41
2008-09	126	2236	113	15	21	7	8	51
2009-10	156	2423	164	19	32	4	4	59
2010-11	167	1806	79	11	28	5	2	46
2011-12	149	1939	108	12	26	8	11	57
2012-13	140	2221	104					61

**Table 20. Female fisher (*Pekania pennanti*) mean maximum distance moved on the east side, west side and total for the years 2005-06 and 2012-13 on the Hoopa fisher study area, Humboldt County, CA.**

Female Fishers	Sample Size		Mean Distance m	
	2005-06	2012-13	2005-06	2012-13
East	5	4	3302	3815
West	7	8	3052	2336
Total	12	12	3156	2829

**Table 21. Lambda random effects model results for fishers (*Pekania pennanti*) within the Hoopa density study area, Humboldt County, CA 2005-06 to 2011-12.**

<b>Model: Both Sexes</b>	QAICc	Delta QAICc	AICc Weights	Model Likelihood	Num. Par	QDeviance
{Phi(t) p(t) Lambda(g*t) PIM: Random Effects Trace G=1.0000000} Means}	800.406	0.000	0.437	1.000	20.0	100.995
{Phi(t) p(t) Lambda(g*t) PIM: Random Effects Trace G=2.0000000} Trend}	802.124	1.718	0.185	0.424	21.0	100.504
{Phi(t) p(t) Lambda(g*t) PIM: Random Effects Trace G=2.0000000} M Means}	802.340	1.934	0.166	0.380	21.0	100.719
{Phi(t) p(t) Lambda(g*t) PIM: Random Effects Trace G=3.0000000} M_T F(.)}	803.950	3.545	0.074	0.170	22.0	100.110
{Phi(t) p(t) Lambda(g*t) PIM: Random Effects Trace G=3.0000000} T+TT}	804.317	3.911	0.062	0.142	22.0	100.476
{Phi(t) p(t) Lambda(g*t) PIM: Random Effects Trace G=3.0000000} FT M(.)}	804.836	4.430	0.048	0.109	22.0	100.995
{Phi(t) p(t) Lambda(g*t) PIM: Random Effects Trace G=4.0000000} MT FT}	806.197	5.791	0.024	0.055	23.0	100.125
{Phi(g*t) p(t) Lambda(g*t) PIM: Random Effects Trace G=1.0000000} Means}	810.309	9.903	0.003	0.007	28.0	92.917
{Phi(t) p(t) Lambda(g*t) PIM}	821.297	20.891	0.000	0.000	33.0	92.300
{Phi(g*t) p(t) Lambda(g*t) PIM}	826.350	25.944	0.000	0.000	39.0	83.039
{Global PIM}	850.497	50.091	0.000	0.000	50.0	79.774

**Table 22. Lambda random effects model results for male fishers (*Pekania pennanti*) within the Hoopa density study area, Humboldt County, CA 2005-06 to 2011-12.**

<b>Model: Males Only</b>	QAICc	Delta QAICc	AICc Weights	Model Likelihood	Num. Par	QDeviance
{Phi(t) p(t) Lambda(t) PIM: Random Effects Trace G=1.0000000} Means}	553.235	0.000	0.540	1.000	18.0	56.971
{Phi(t) p(t) Lambda(t) PIM: Random Effects Trace G=3.0000000} Quad Trend}	554.829	1.594	0.243	0.451	20.0	53.523
{Phi(t) p(t) Lambda(t) PIM: Random Effects Trace G=2.0000000} Trend}	555.063	1.828	0.216	0.401	19.0	56.293
{Phi(t) p(t) Lambda(t) PIM}	566.907	13.671	0.001	0.001	25.0	52.420

**Table 23 Lambda random effects model results for female fishers (*Pekania pennanti*) within the Hoopa density study area, Humboldt County, CA 2005-06 to 2011-12.**

<b>Model: Females Only</b>	QAICc	Delta QAICc	AICc Weights	Model Likelihood	Num. Par	QDeviance
{Phi(t) p(t) Lambda(t) PIM: Random Effects Trace G=1.0000000} Means}	384.332	0.000	0.649	1.000	18.0	43.973
{Phi(t) p(t) Lambda(t) PIM: Random Effects Trace G=2.0000000} Trend}	386.474	2.142	0.222	0.343	19.0	43.778
{Phi(t) p(t) Lambda(t) PIM: Random Effects Trace G=3.8170123} Quad Trend}	387.610	3.278	0.126	0.194	20.8	40.616
{Phi(t) p(t) Lambda(t) PIM}	395.324	10.992	0.003	0.004	25.0	38.174

**Table 24. Fisher (*Pekania pennanti*) lambda estimates from random effects models, SE, 95% CI median c-hat and sample sizes for the population as a whole, males and females separately, Hoopa fisher density study area, Humboldt County, CA, 2005-06 to 2011-12.**

	Lambda	SE	lower	upper	Median c-hat	Num. Animals	Effective Sam. Size
Both Sexes Combined	0.992	0.055	0.883	1.100	2.16	221	433
Males Only	0.912	0.069	0.777	1.047	1.409	103	179
Females Only	1.038	0.081	0.881	1.196	2.579	118	254

**Table 25. Fisher (*Pekania pennanti*) apparent survival model results for the Hoopa density study area, Humboldt County, CA, 2004-05 to 2012-13.**

Model	QAICc	Delta QAICc	AICc Weights	Model Likelihood	Num. Par	QDeviance
{Phi(MT, F.) p(T+Core)}	377.6543	0	0.2535	1	6	365.3656
{Phi(MT, FT) p(T+Core)}	377.8742	0.2199	0.22711	0.8959	7	363.488
{Phi(MT, F-LnT) p(T+Core)}	378.4079	0.7536	0.17391	0.686	7	364.0217
{Phi(s) p(T+Core)}	378.7628	1.1085	0.14564	0.5745	5	368.5573
{Phi(MT, FT+TT) p(T+Core)}	379.7786	2.1243	0.08764	0.3457	8	363.2803
{Phi(s+T) p(T+Core)}	380.7297	3.0754	0.05447	0.2149	6	368.441
{Phi(a+s) p(T+Core)}	382.2123	4.558	0.02596	0.1024	7	367.8261
{Phi(s+T+TT) p(T+Core)}	382.6652	5.0109	0.0207	0.0817	7	368.279
{Phi(a+s+T) p(T+Core)}	384.201	6.5467	0.0096	0.0379	8	367.7028
{Phi(.) p(T+Core)}	388.3766	10.7223	0.00119	0.0047	4	380.2401
{Phi(s+t) p(T+Core)}	391.9947	14.3404	0.00019	0.0007	12	366.8999
{Phi(s+t) p(T+Core)}	394.1816	16.5273	0.00007	0.0003	13	366.8999
{Phi(g+t) p(T+Core)}	395.8115	18.1572	0.00003	0.0001	14	366.3274
{Phi(a+t) p(T+Core)}	402.2493	24.595	0	0	12	377.1546
{Phi(g*t) p(T+Core)}	421.7831	44.1288	0	0	35	342.1648
{Global PIM Phi(g*t) p(g*t)}	490.1934	112.5391	0	0	64	326.4853

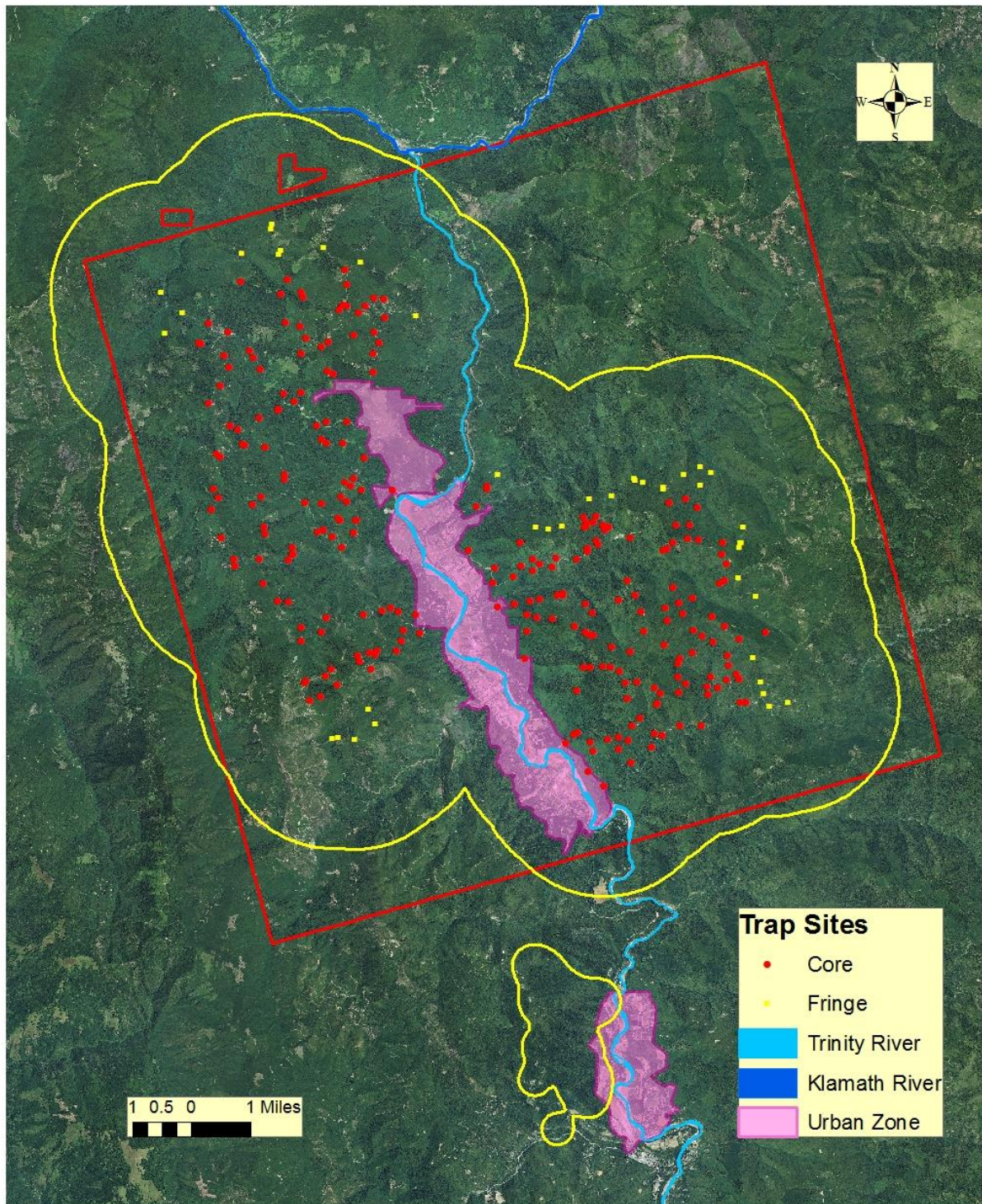
**Table 26. Model results of female fisher (*Pekania pennanti*) apparent survival using 9 years of capture-mark-recapture data (2004-05 to 2012-13) with habitat covariates, Hoopa Valley Indian Reservation, Humboldt County, CA.**

Model	QAICc	Delta QAICc	AICc Weights	Model Likelihood	Num. Par	QDeviance
{Phi(T+SX) p(Core)}	163.451	0.000	0.093	1.000	5	153.083
{Phi(T+TotRds) p(Core)}	163.523	0.072	0.090	0.965	5	153.155
{Phi(T+cSX) p(Core)}	163.545	0.094	0.089	0.954	5	153.177
{Phi(T+cTotRds) p(Core)}	163.588	0.137	0.087	0.934	5	153.220
{Phi(T) p(Core)}	164.230	0.779	0.063	0.678	4	155.986
{Phi(T+MOF) p(Core)}	164.274	0.824	0.062	0.662	5	153.906
{Phi(T+cMOF) p(Core)}	164.346	0.895	0.060	0.639	5	153.978
{Phi(T+Managed) p(Core)}	164.359	0.908	0.059	0.635	5	153.991
{Phi(.) p(Core)}	164.799	1.348	0.047	0.510	3	158.654
{Phi(T+SX+cTot_Rds) p(Core)}	165.120	1.669	0.040	0.434	6	152.601
{Phi(T+SX+Tot_Rds) p(Core)}	165.256	1.805	0.038	0.406	6	152.738
{Phi(T+cSX+Tot_Rds) p(Core)}	165.365	1.914	0.036	0.384	6	152.846
{Phi(T+SX+MOF) p(Core)}	165.601	2.150	0.032	0.341	6	153.083
{Phi(g+T) p(Core)}	165.632	2.181	0.031	0.336	5	155.264
{Phi(T+Tot_Rds+MOF) p(Core)}	165.644	2.193	0.031	0.334	6	153.126
{Phi(T+cSX+MOF) p(Core)}	165.694	2.243	0.030	0.326	6	153.175
{Phi(T+TT) p(Core)}	165.914	2.463	0.027	0.292	5	155.546
{Phi(T+D_Rds) p(Core)}	165.986	2.535	0.026	0.282	5	155.618
{Phi(T+OPEN) p(Core)}	166.270	2.819	0.023	0.244	5	155.902
{Phi(T+Other) p(Core)}	166.324	2.873	0.022	0.238	5	155.956
{Phi(age+T+TT) p(Core)}	167.401	3.950	0.013	0.139	6	154.882
{Phi(t) p(Core)}	172.649	9.199	0.001	0.010	9	153.517
{Phi(g*t) p(Core)}	179.315	15.864	0.000	0.000	14	148.588
{Phi(g*t) p(g+Core)}	181.170	17.719	0.000	0.000	15	148.033
{Phi(g*t) p(T+Core)}	186.349	22.898	0.000	0.000	17	148.296
{Phi(g*t) p(g+T)}	195.849	32.398	0.000	0.000	18	155.289
{Phi(g*t) p(g+t)}	198.823	35.372	0.000	0.000	21	150.537
{Global PIM}	215.628	52.177	0.000	0.000	30	142.149



Figure 1 Location of the Hoopa Valley Indian Reservation (red outline) in northeastern Humboldt County (Yellow outline), CA.





**Figure 2** Hoopa Fisher study area (Large yellow outlined area = capture-mark-recapture study area, which also contains all but one of the 95% fixed kernel home ranges, small yellow outline) with capture-mark-recapture trap sites, Hoopa Valley Indian Reservation (red square outline), Humboldt County, CA.



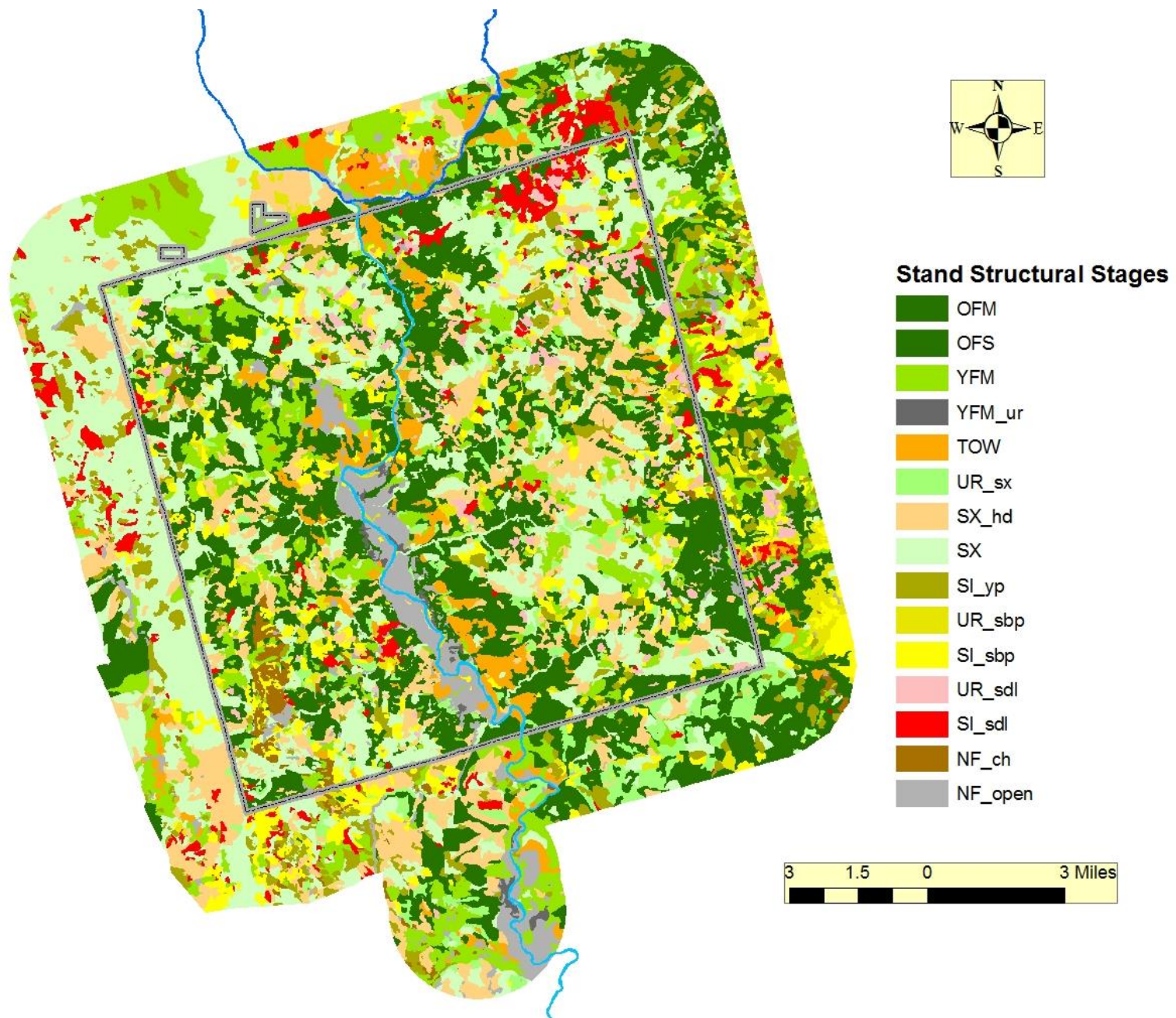
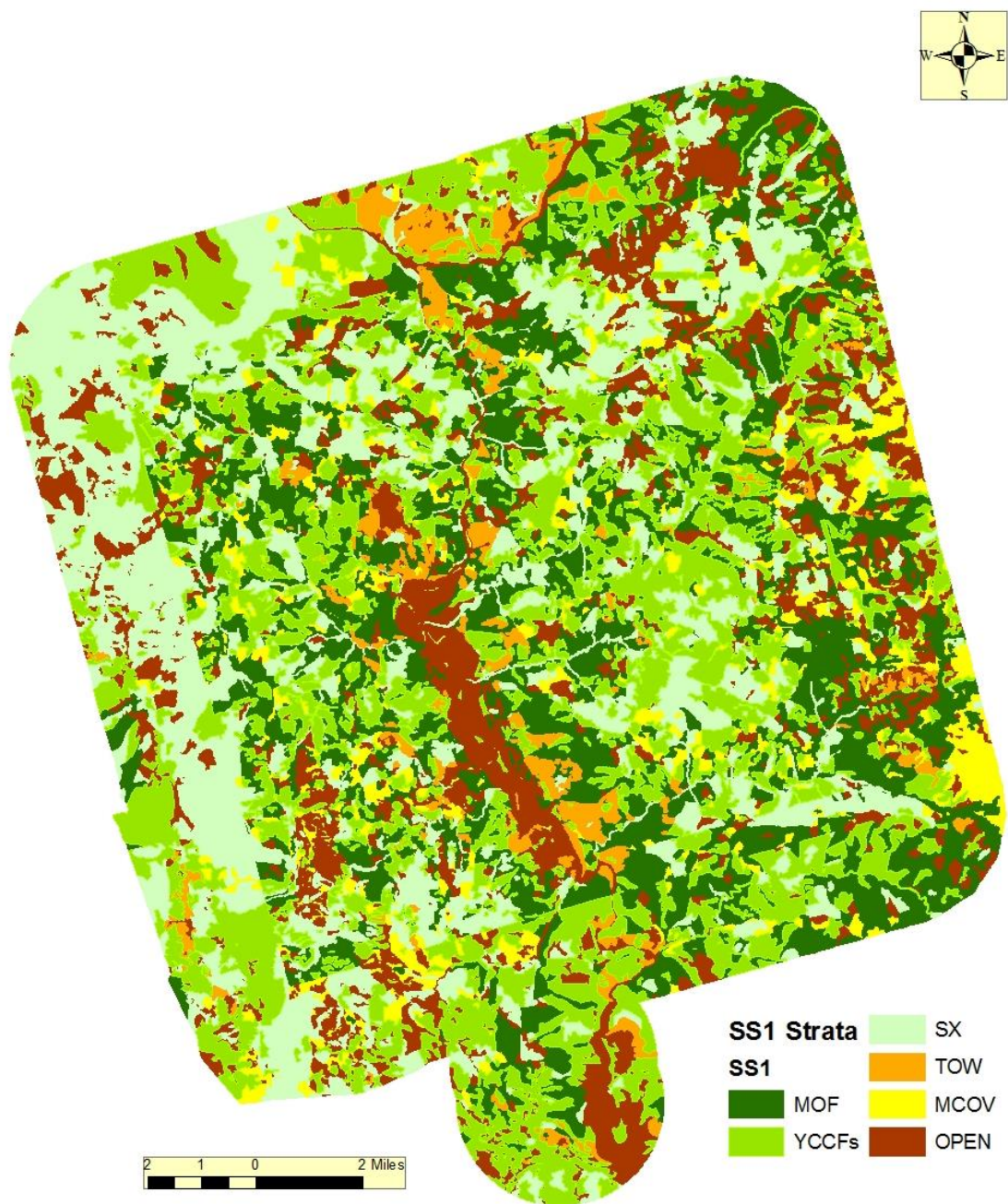


Figure 3 Hoopa Valley Indian Reservation (Gray square outline) and surrounding area stand structural stages, Humboldt County, CA.

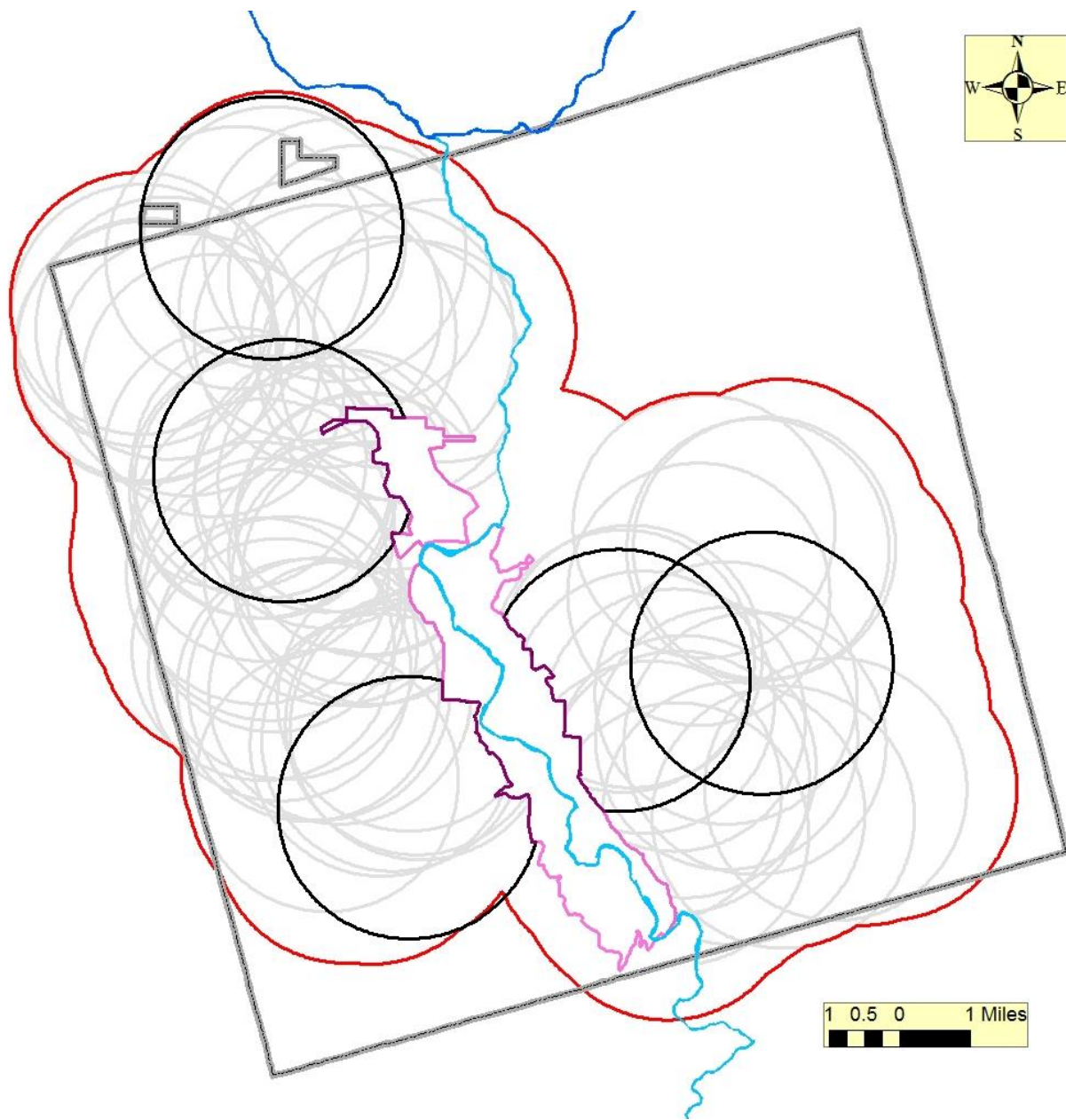


**Figure 4** Stand Seral Stage strata 1 used for the basis of much of the fisher habitat analysis on the Hoopa fisher study area, Humboldt County, CA.



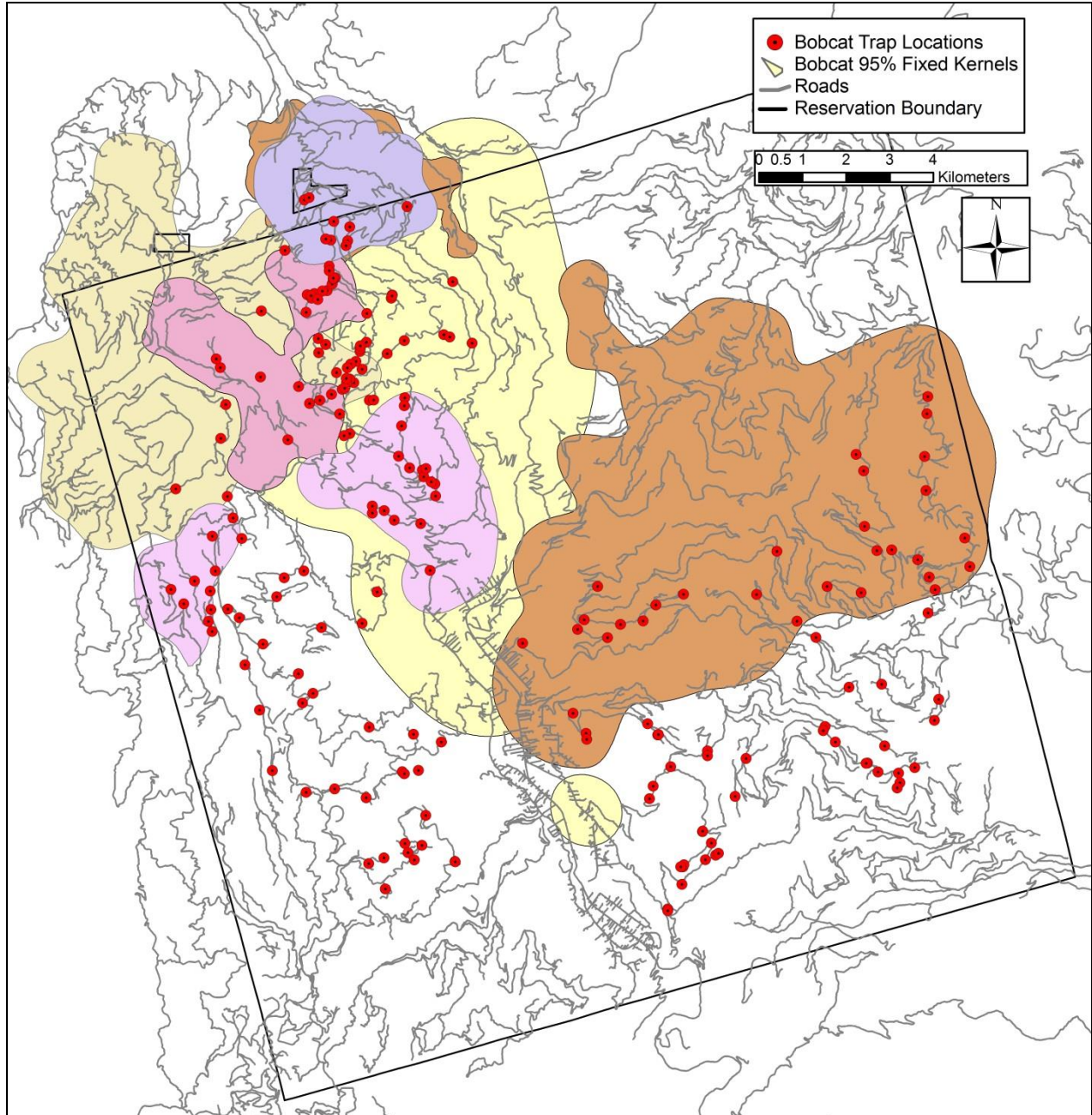


**Figure 5** Stand seral strata 2 used for the development of some additional habitat covariates that were used for the fisher habitat analysis, pooling MOF and YCCF resulted in a 3<sup>rd</sup> strata layer with 2 strata (forested = FOR and Non-Forest = OP or OTHER) on the Hoopa fisher study area, Humboldt County, CA.

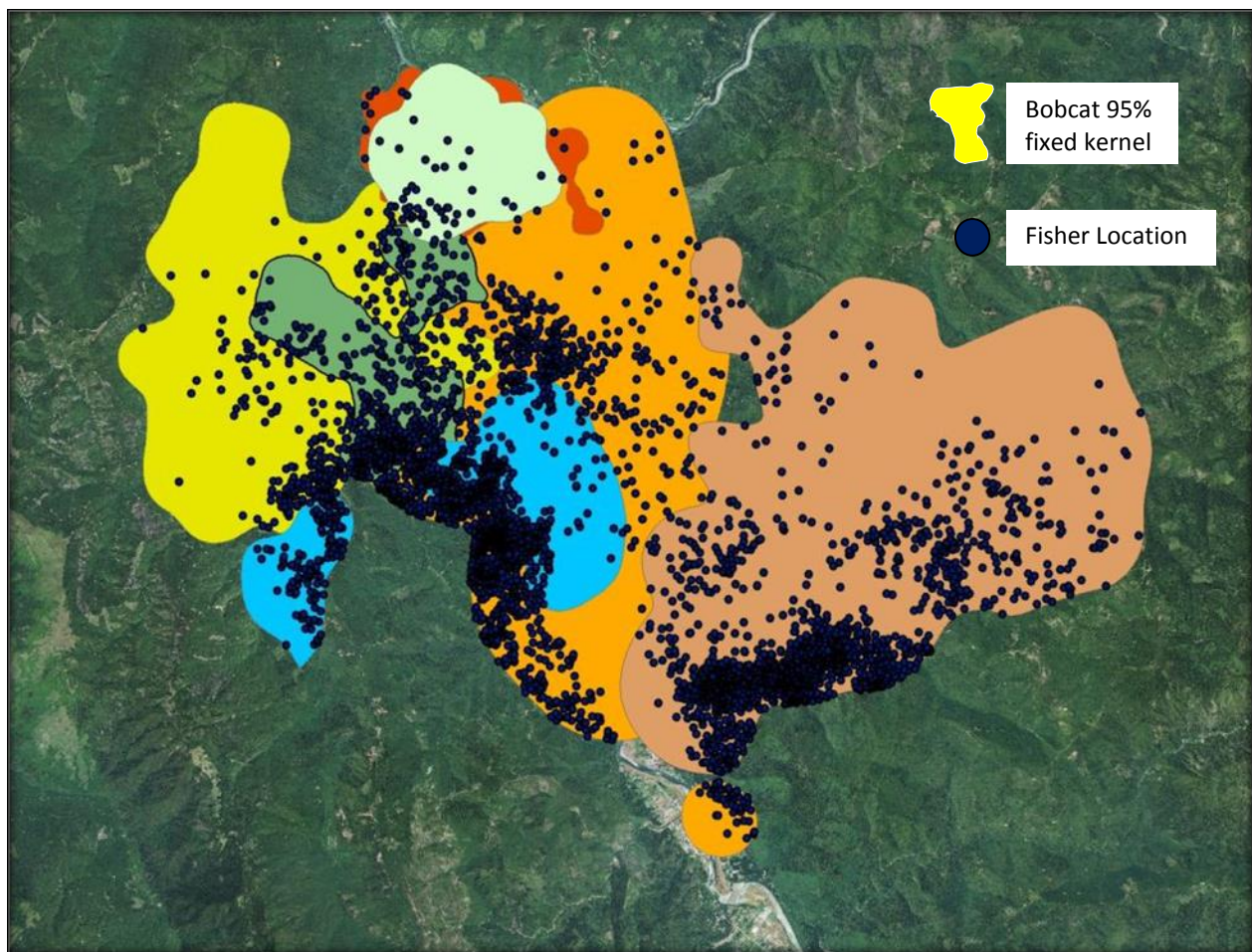


**Figure 6** Examples of 3000 buffers truncated at the edge of the urban zone and those left intact (black) and the total population of buffers used for calculating habitat covariates for use in the female apparent survival with habitat covariates analysis. Red outline represents the effective trap area of the capture-mark-recapture study area. Hoopa fisher study area, Humboldt County, CA. 2004-05 to 2012-13.





**Figure 7** Map of Hoopa Valley Indian Reservation, Hoopa, CA and distribution of traps set for bobcats (*Lynx rufus*), 2010 – 2012. Also shown are the 95% fixed kernels for seven bobcats captured and monitored with GPS and VHF collars between February 6, 2011 and October 31, 2012.



**Figure 8** Distribution of fisher (*Martes pennanti*) locations falling within bobcat (*Lynx rufus*) 95% fixed kernels used to assess habitat-mediated predation risk for fishers at Hoopa Valley Indian Reservation, 2010 – 2012.

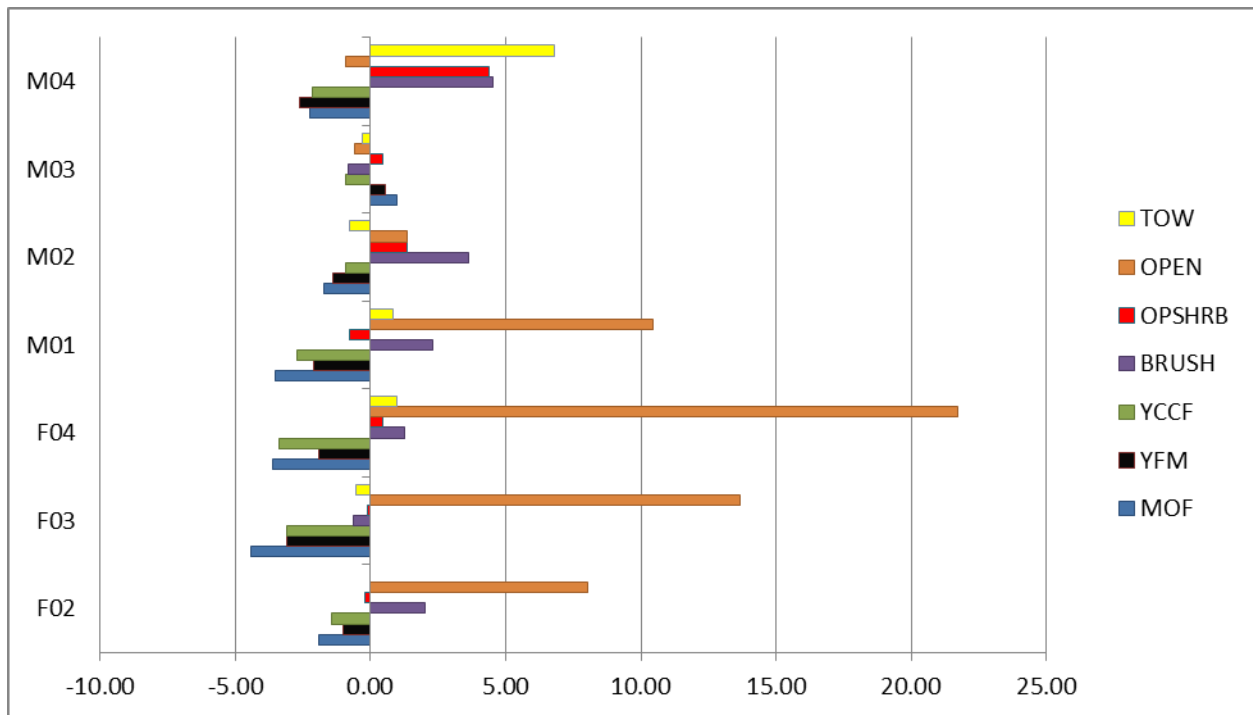


Figure 9. Individual bobcat ( $n=7$ ) habitat selection indices for seven habitat strata types within each bobcat's 95% fixed kernel home range at Hoopa Valley Indian Reservation, Hoopa, CA, built with data collected from GPS and VHF collars on seven bobcats between February 6, 2011 and October 31, 2012.



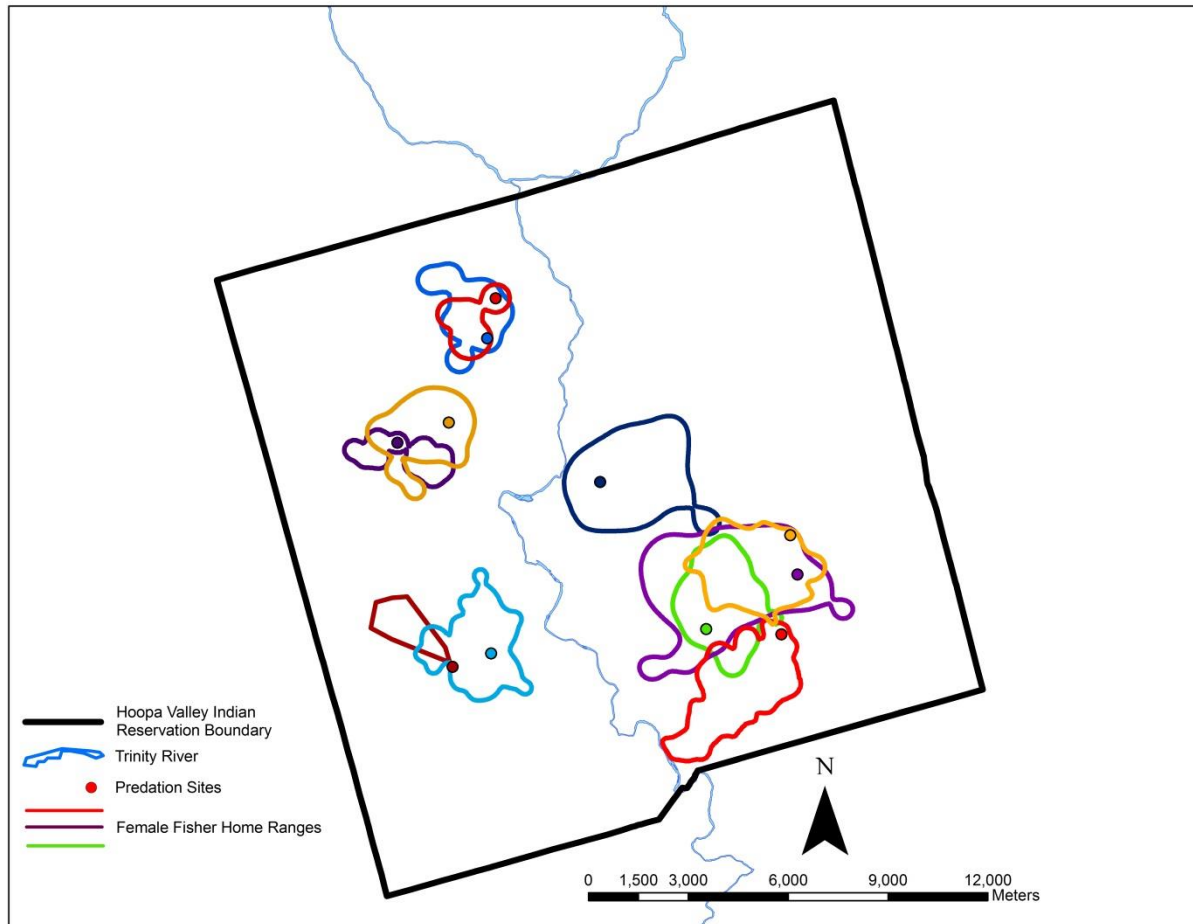
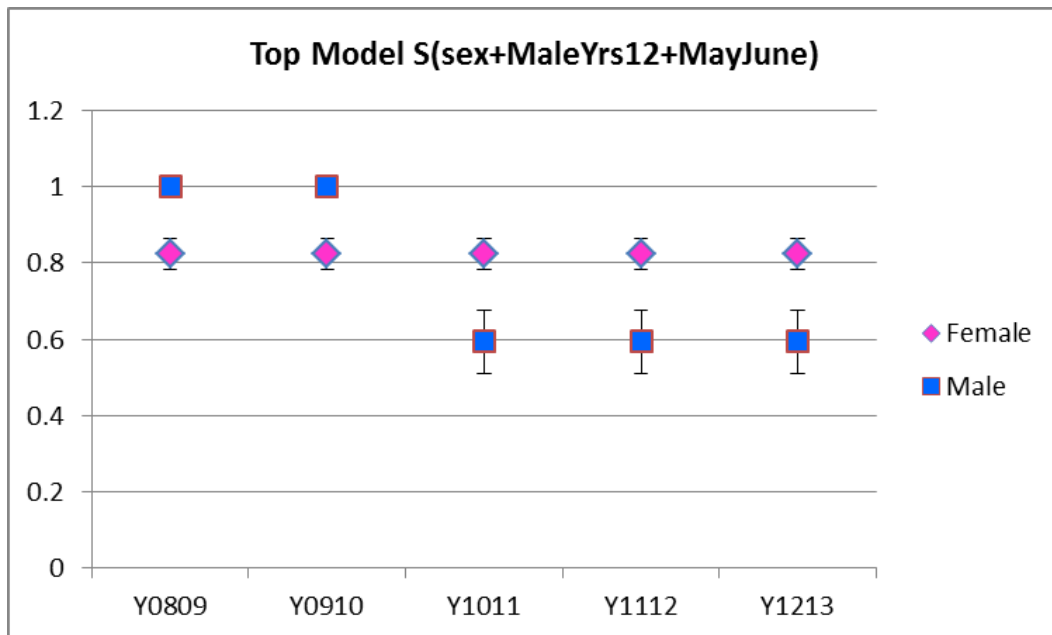
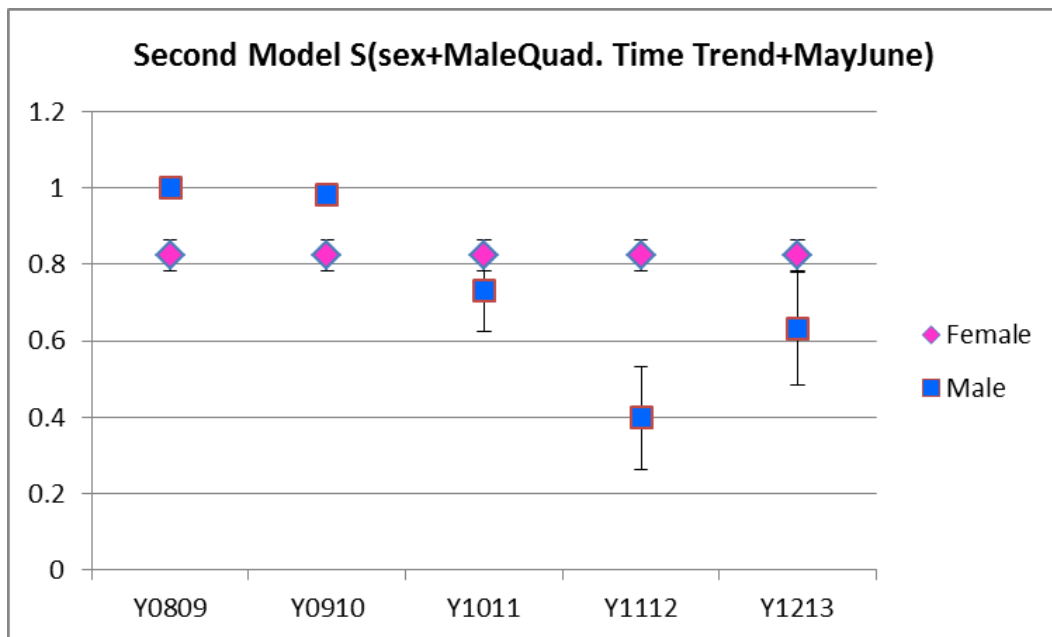


Figure 10. Map of the study area, Hoopa Valley Indian Reservation in north Coastal California showing 95% fixed kernel home ranges of eleven female fishers (*Pekania pennanti*, Higley et al. 2013) that were killed by bobcats (*Lynx rufus*), and their predation sites between April 28, 2005 and April 17, 2013. Each fisher's predation site is the same color as its home range.

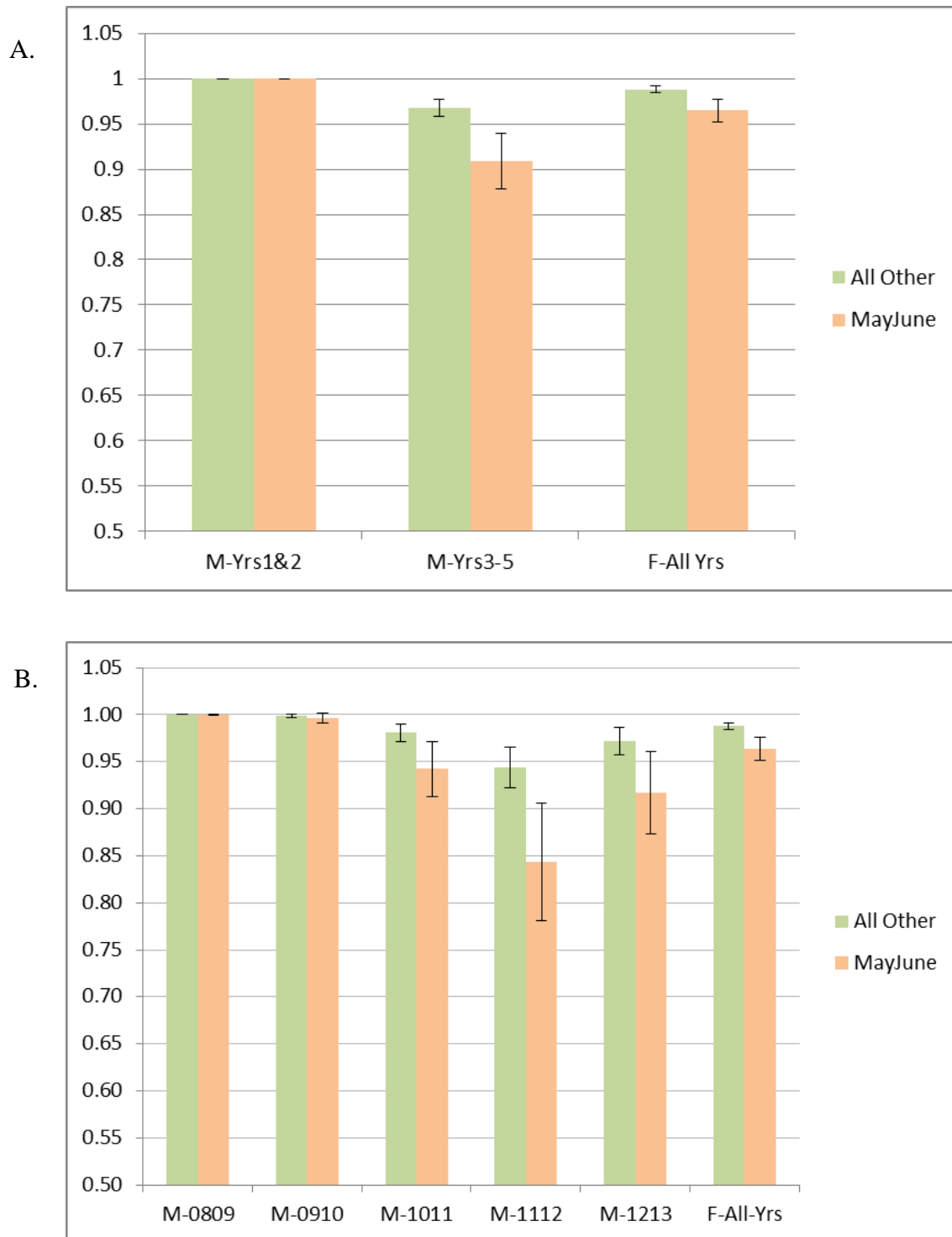
A.



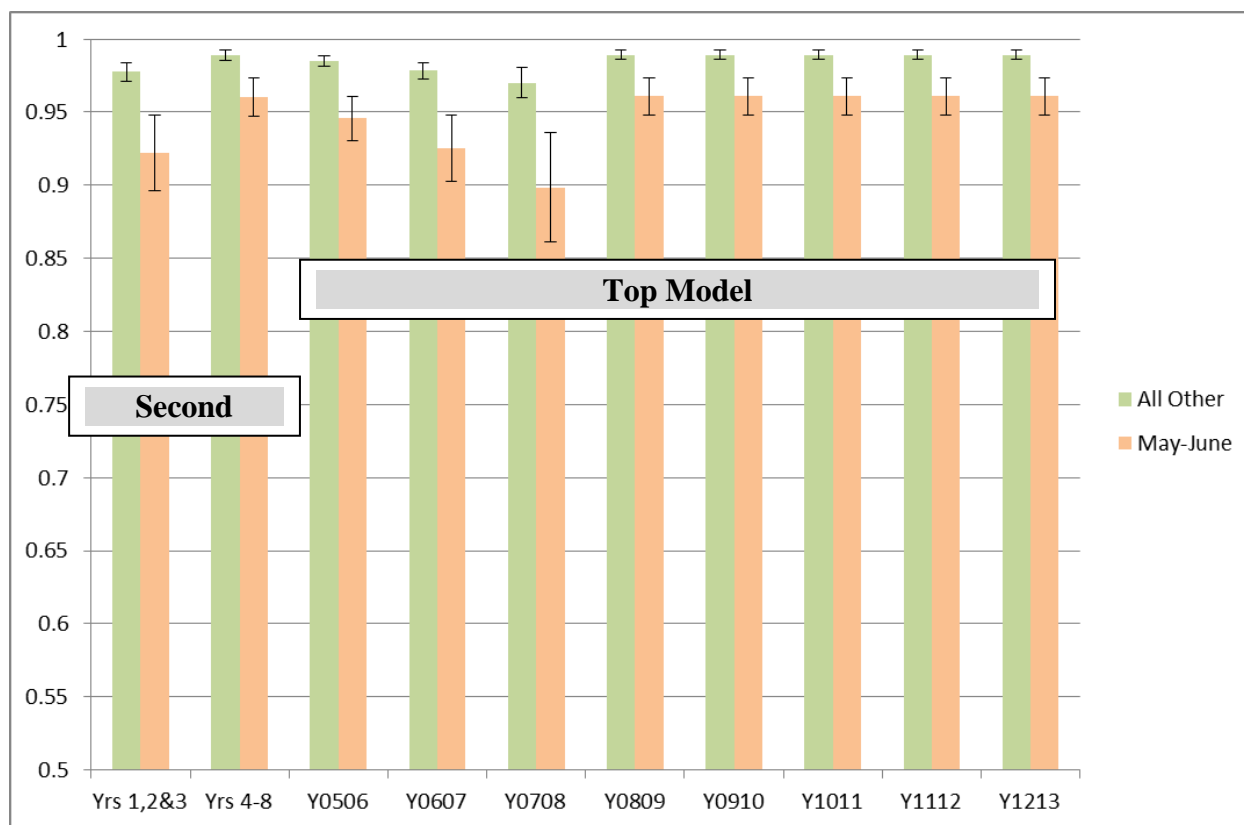
B.



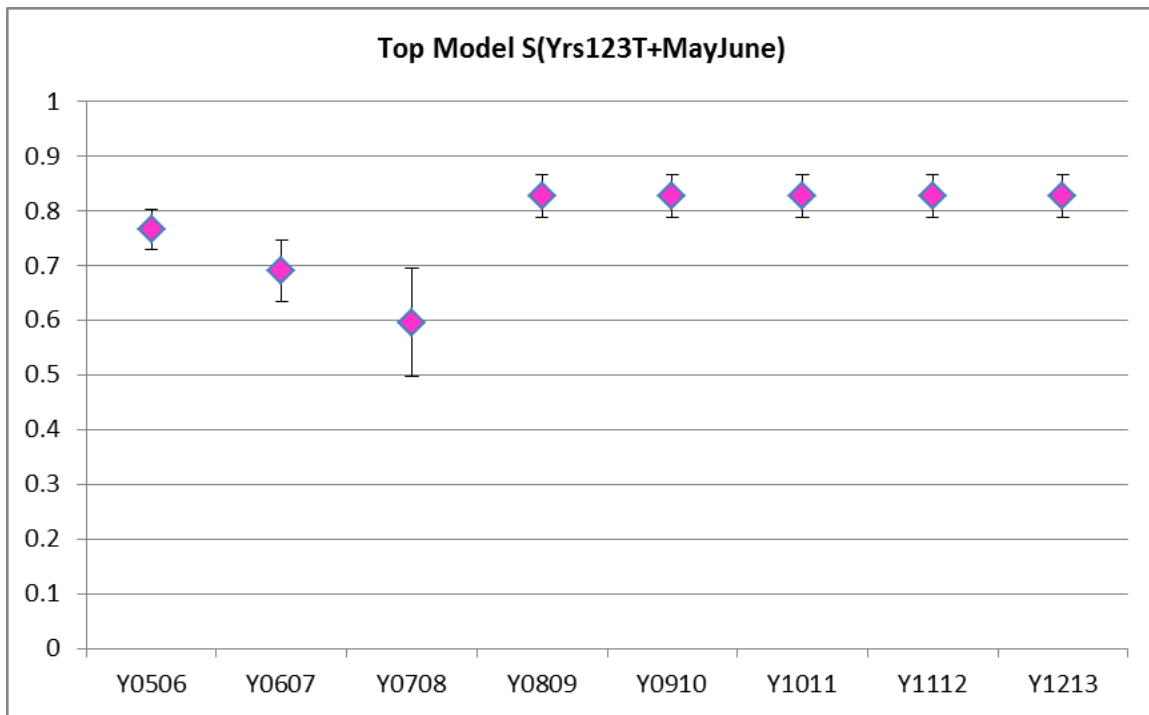
**Figure 9** Top 2 competitive models of fisher known fate survival including both sexes. The top model (A.) included different estimates of male and female survival with constant female survival and constant survival of males in year 1 and 2 with a lower constant survival in years 3-5. Both sexes showed different (lower) monthly survival in the months of May and June compared to the rest of the year and differences in survival between sexes through all of the competitive models. The second model included a quadratic time trend on male survival and constant female survival. Error bars are standard errors of the estimates.



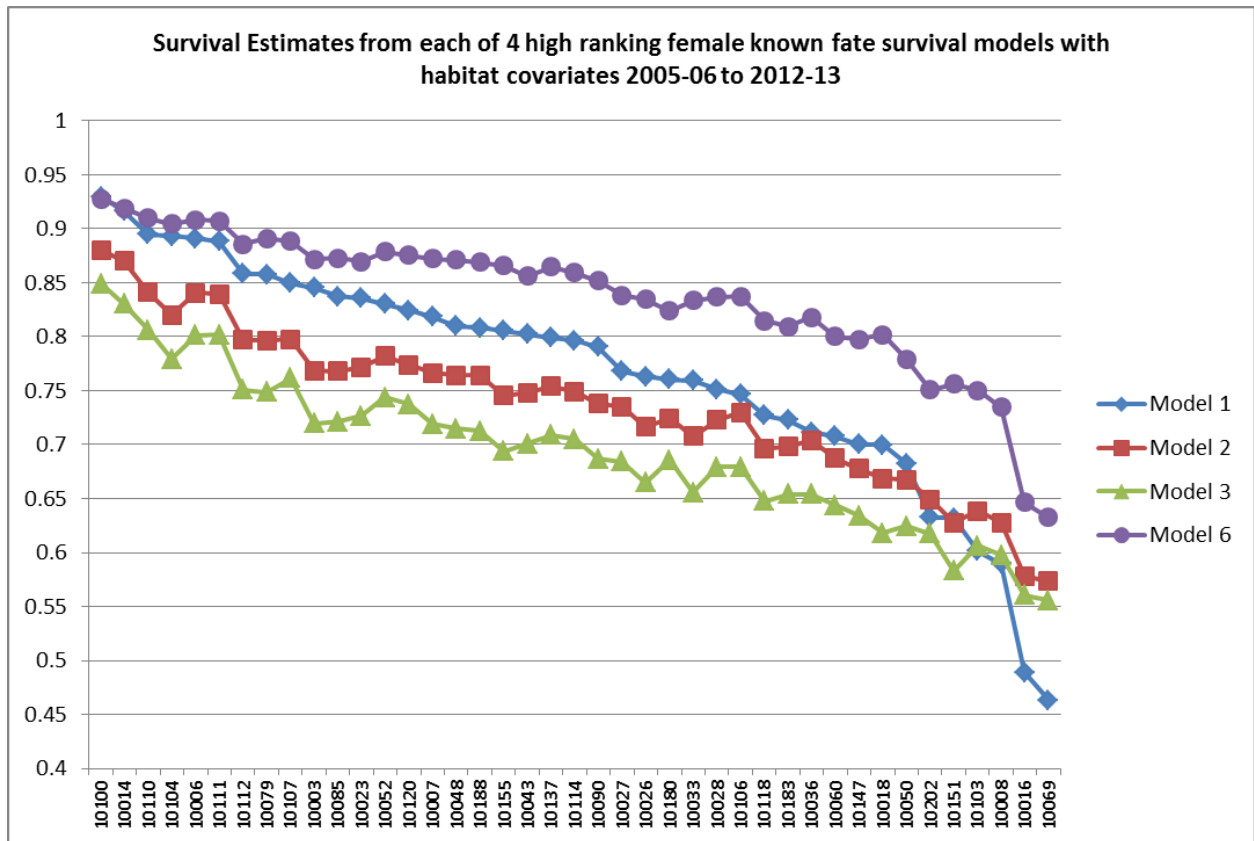
**Figure 10** Estimates of monthly survival resulting from the top 2 known fate models which included both male and female fishers. The top model (A.) included constant survival across all years for females with lower May-June monthly survival and males had higher annual survival in years 1 and 2 compared to years 3-5. The second model (B.) included a quadratic time trend on male survival and lower May-June survival of both sexes.



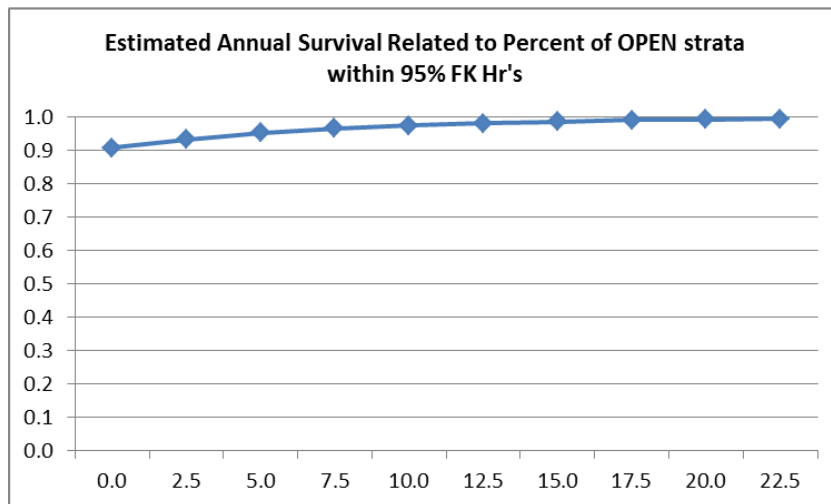
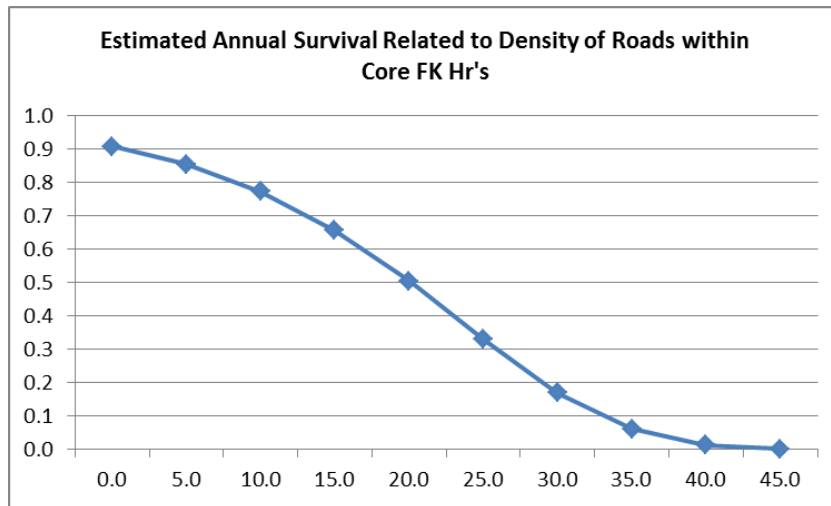
**Figure 11** Estimates of female fisher survival by year and month for the top 2 female only known fate models. The top model included a downward trend on female survival for the years 2005-06 to 2007-08 and then constant annual survival thereafter. The second model included constant female survival across 2 time periods with lower survival in the years 2005-06 to 2007-08 and higher annual survival in years 2008-09 to 2012-13. In all of the competitive models there was a May-June effect where survival is lower in May and June than all of the other months.



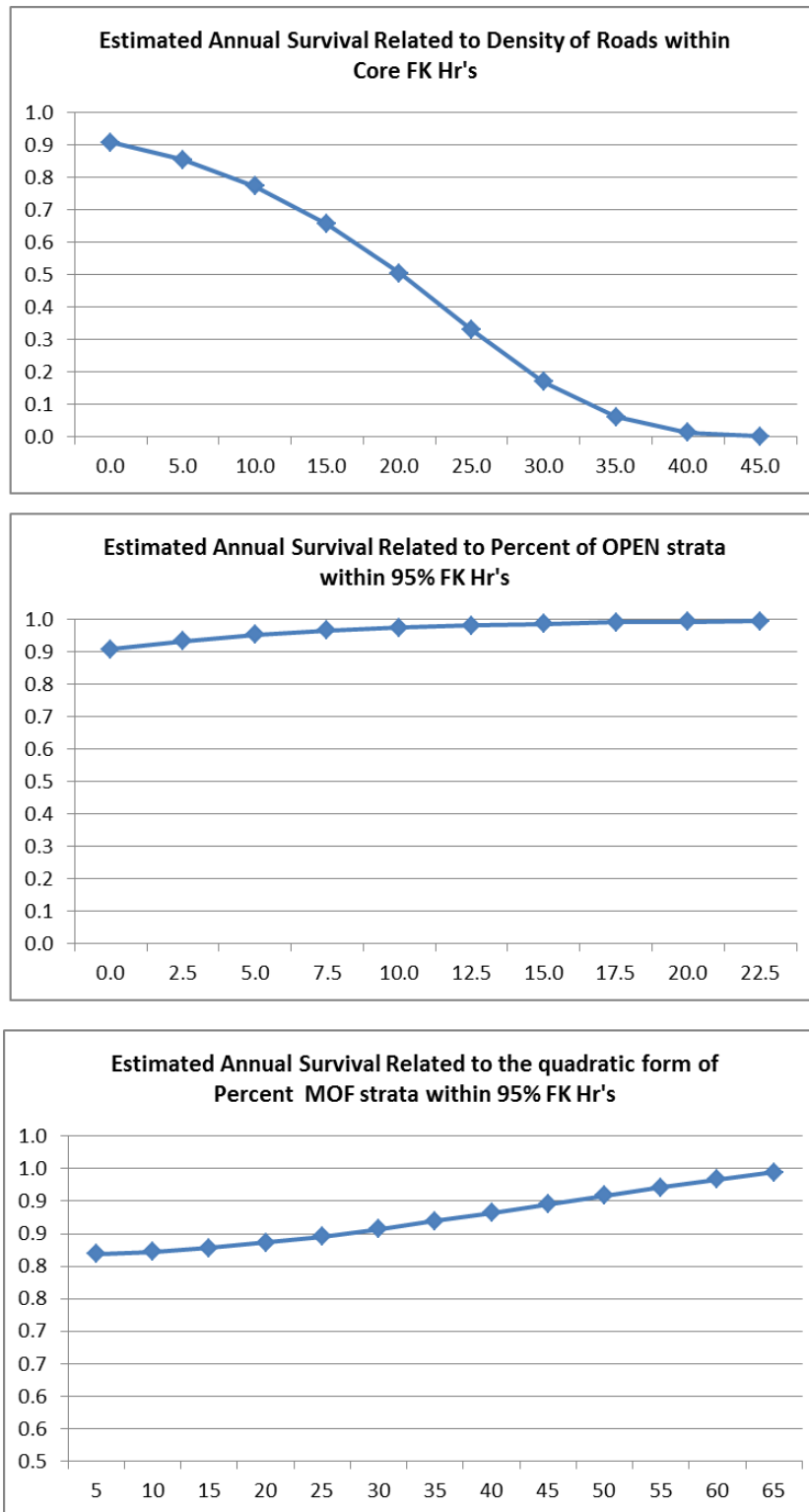
**Figure 12 Annual survival estimates and standard error derived from the top female-only known fate survival analysis which included a downward time trend on survival for the years 2005-06 to 2007-08 and then constant, and higher survival for the years 2008-09 to 2012-13.**



**Figure 13** Estimates of individual annual female survival based on four top ranking competitive models using 8 years of known fate monitoring data. All four of the models include a negative impact of the density of drivable roads within the animals core fixed kernel home range and a positive effect of an increase in percent open strata within the animals 95% fixed kernel home range. Model 1 includes only those 2 variables while Models 2 and 3 also include a positive effect of an increase in mature and older forest strata (percent (model 3) or quadratic form of percent (model 2)) while model 6 includes a negative effect of percent stem exclusion strata within the 95% kernel. Hoopa fisher study area, Humboldt County, CA, 2005-06 to 2012-13.

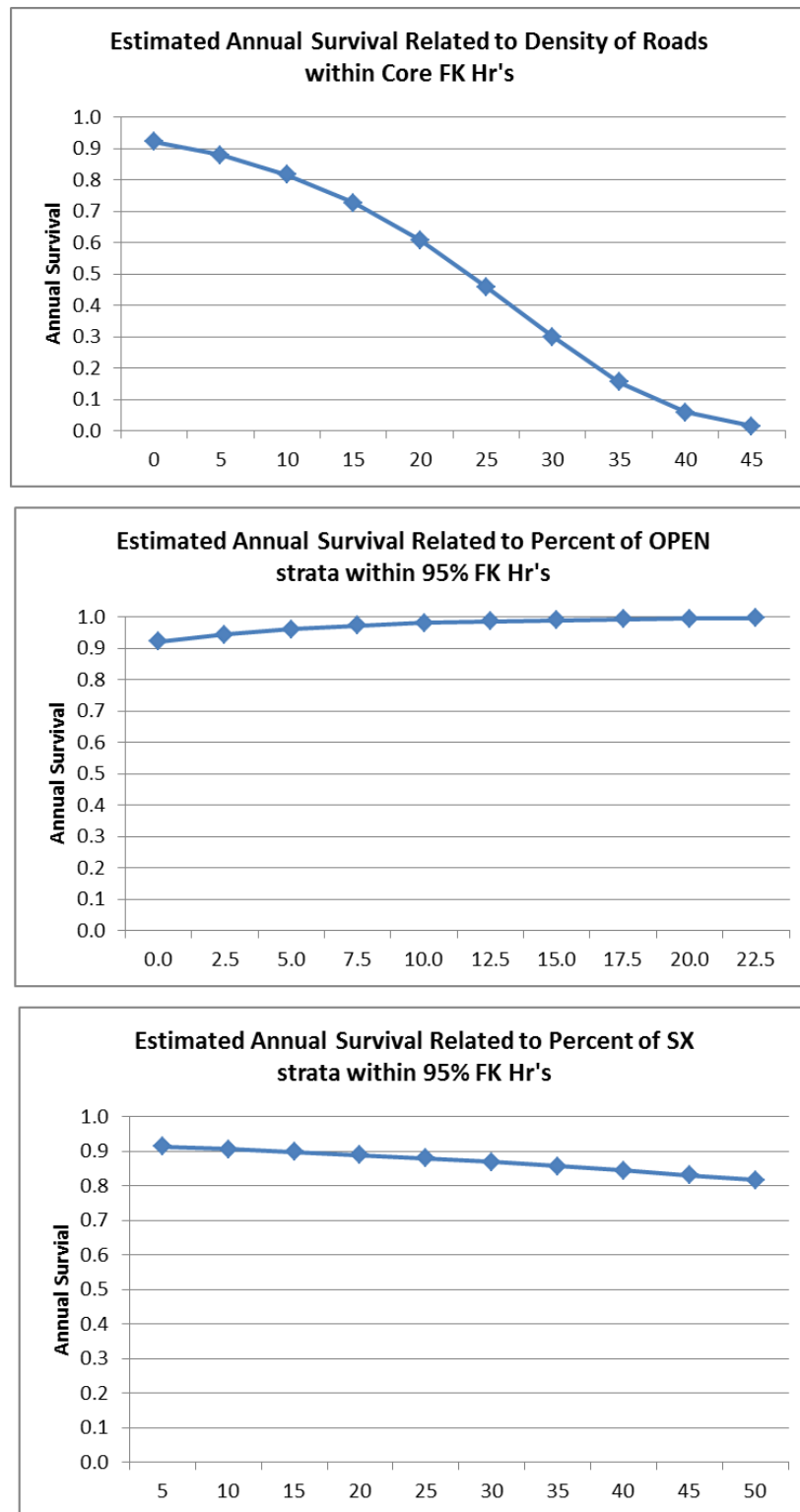


**Figure 14** Estimated annual female survival from the top ranked model including habitat covariates which indicated that increasing density of drivable roads within the core fixed kernel home range had a negative effect while a positive effect on female survival was associated with an increase in percentage of open habitat strata within the 95% fixed kernel home range within the Hoopa fisher study area, Humboldt County, CA.

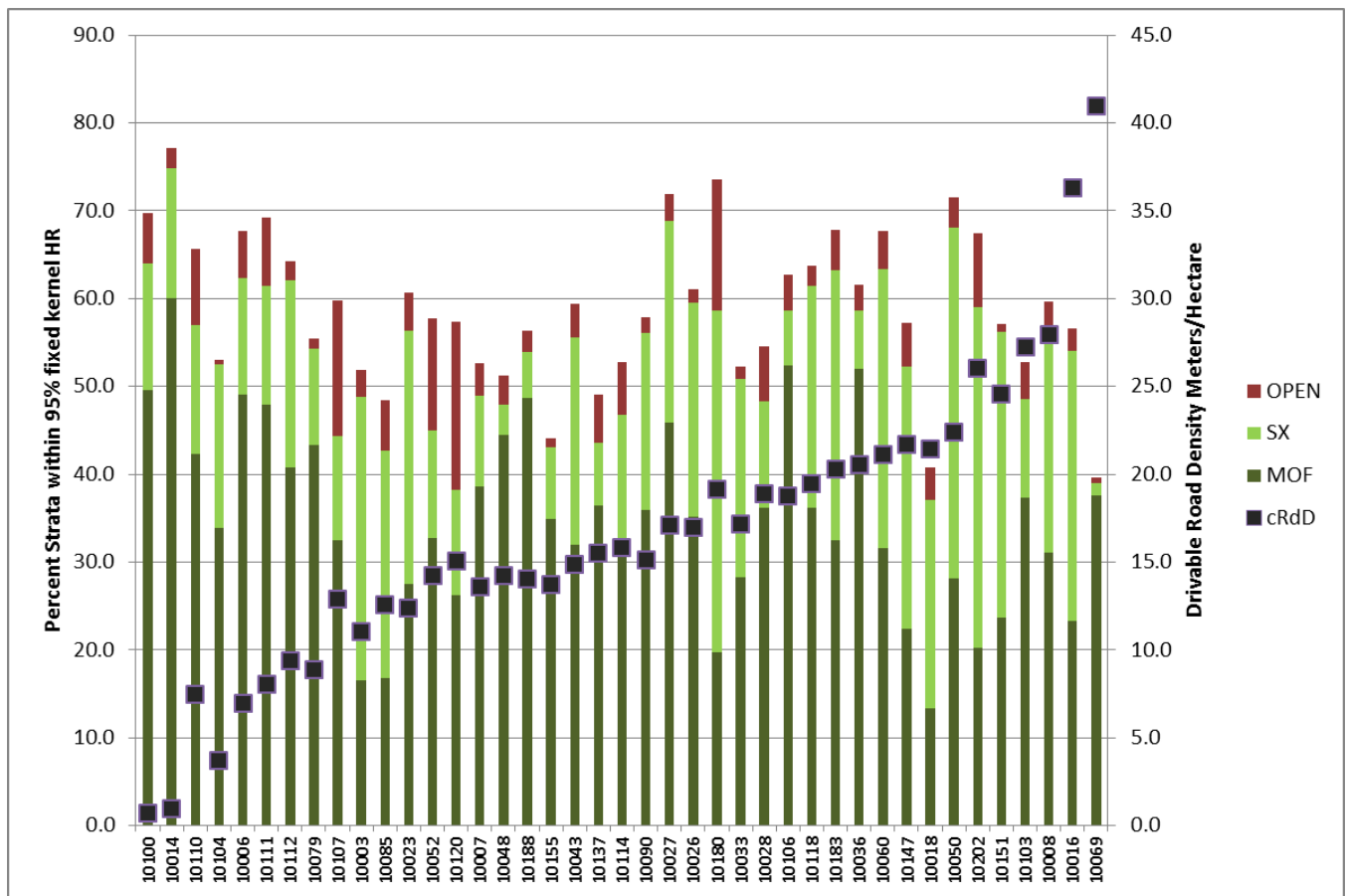


**Figure 15** Estimated annual female survival from the second ranked model (Delta AICc 0.602) including habitat covariates which indicated that increasing density of drivable roads within the core fixed kernel home range had a negative effect while a positive effect on female survival was associated with an increase in percentage of open habitat and mature and older forest strata within the 95% fixed kernel home range within the Hoopa fisher study area, Humboldt County, CA.



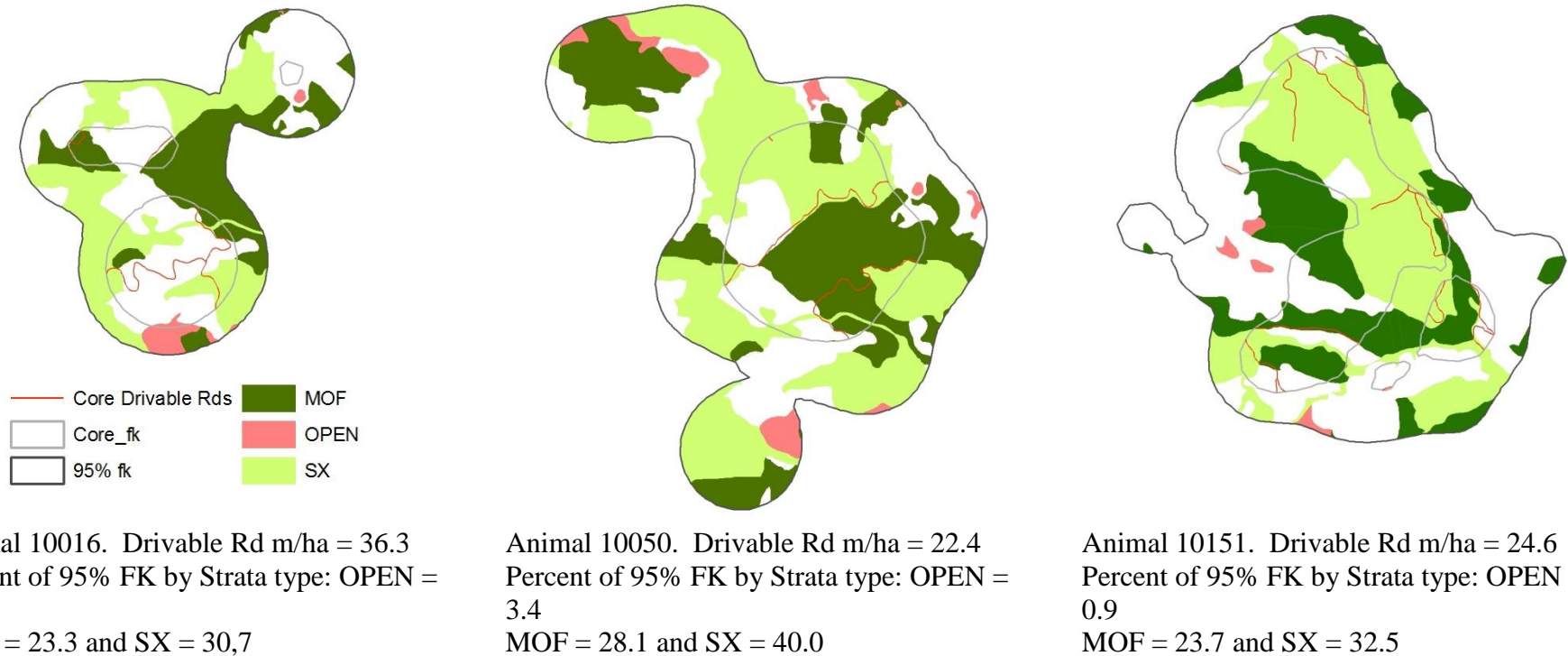


**Figure 16** Estimated annual female survival from the sixth ranked model (Delta AICc 1.143) including habitat covariates which indicated that increasing density of drivable roads within the core fixed kernel home range and increasing percent stem exclusion strata within the 95% fixed kernel had a negative effect while a positive effect on female survival was associated with an increase in percentage of open habitat strata within the 95% fixed kernel home range within the Hoopa fisher study area, Humboldt County, CA



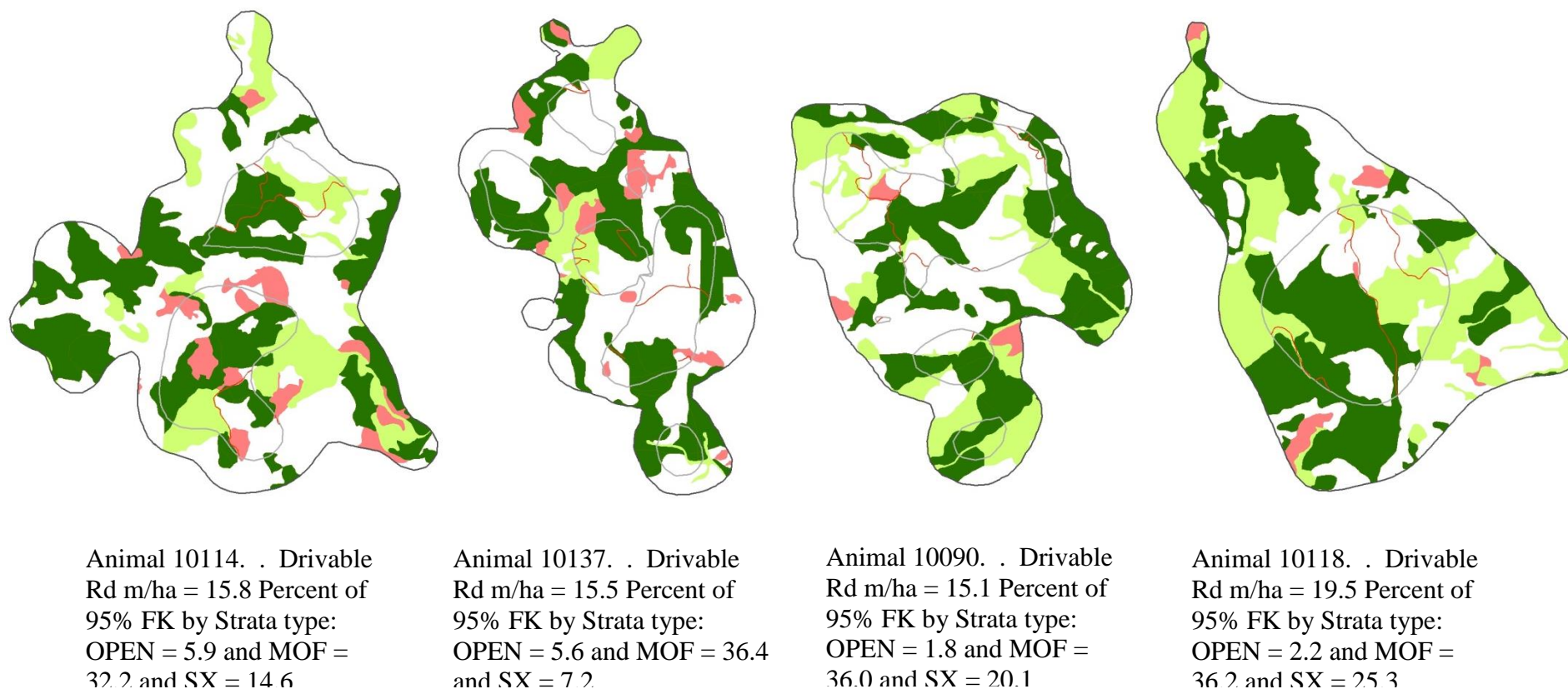
**Figure 17** Percent habitat strata within 95% fixed kernel home ranges of female fishers and drivable road density within core fixed kernel home ranges of 41 female fishers monitored for known fate survival. The individual home ranges are sorted by the estimate of annual survival of the top ranked model from highest to lowest from left to right. The top ranked model and all of the competitive models included a negative effect of core area drivable road density and a positive effect of open strata within the 95% kernel home range. The second and 3 ranked models included a positive effect of percent mature and older forest strata within the 95% kernel while the 6<sup>th</sup> ranked model included a negative effect of the percent of stem exclusion strata within the 95% kernel. Hoopa fisher study area, Humboldt County, CA, 2005-06 to 2012-13.

**Low Estimated Survival across all Models. Scale**

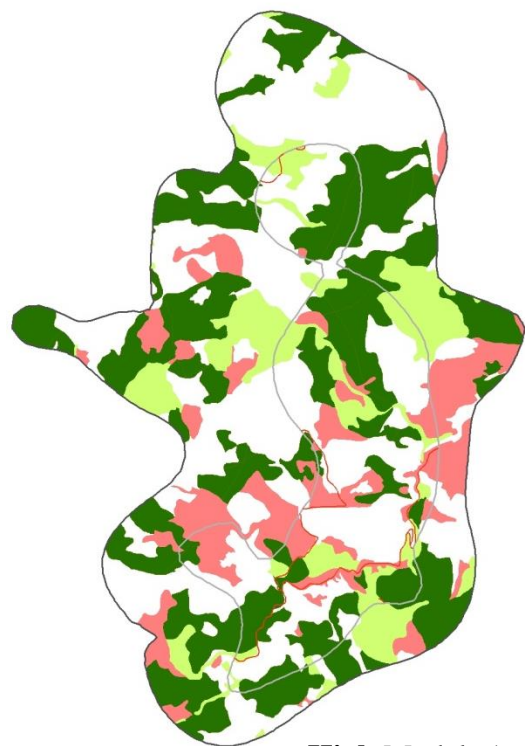


**Figure 18 . Examples of individual home ranges which would have low, moderate or high estimates on survival based on all of the competitive models. The legend is the same for each page. The current page shows examples which represent low survival estimates. All 3 animals have died, 2 from predation and 1 from disease (10151). Average age at time of death was 3.7 years.**

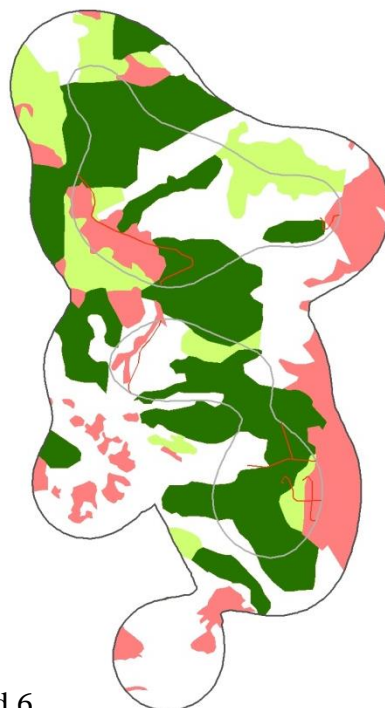
**Moderate Estimated Survival across Models 1 and 6 or 3 and 6. Scale**



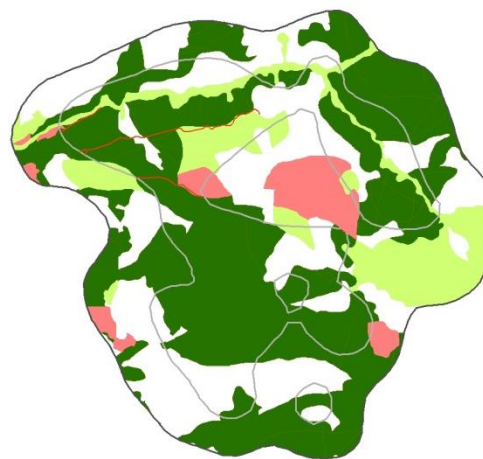
**Figure 20 cont.** These 4 examples all have moderate estimates of survival, 3 of the 4 animals have died 2 confirmed predation and 1 suspected predation (10118). Average age at time of death 6.0 years. Animal 10137 is still alive.



**High Models 1 and 6**



**ligh**



**High Models 3 and 6.**



Animal 10052. Drivable Rd  
m/ha = 14.2 Percent of 95%  
FK by Strata type: OPEN =  
12.8, MOF = 32.8 and SX =  
12.2

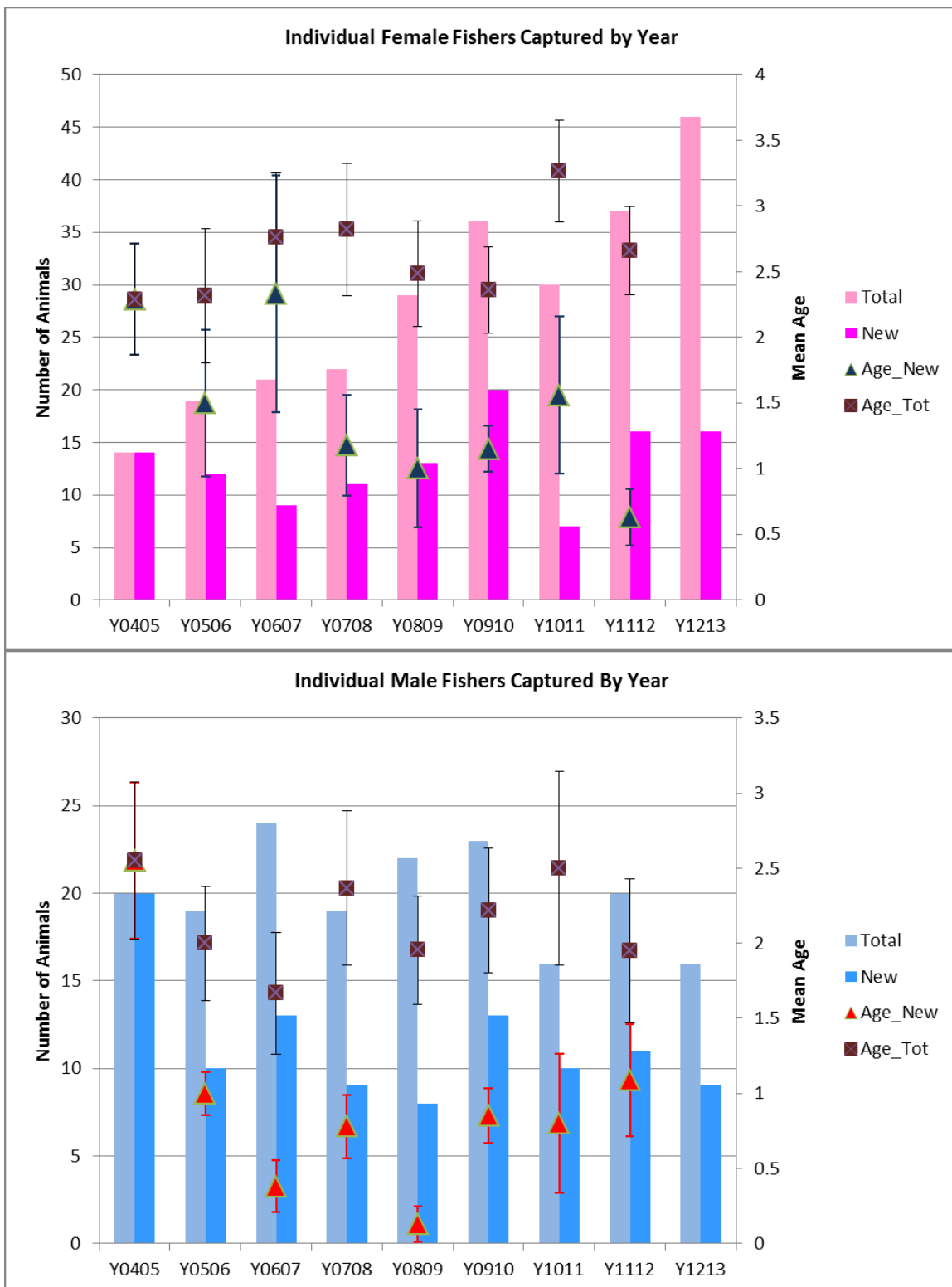
Animal 10107. Drivable Rd  
m/ha = 12.9 Percent of 95%  
FK by Strata type: OPEN =  
15.5, MOF = 32.5 and SX =  
11.8

s 1

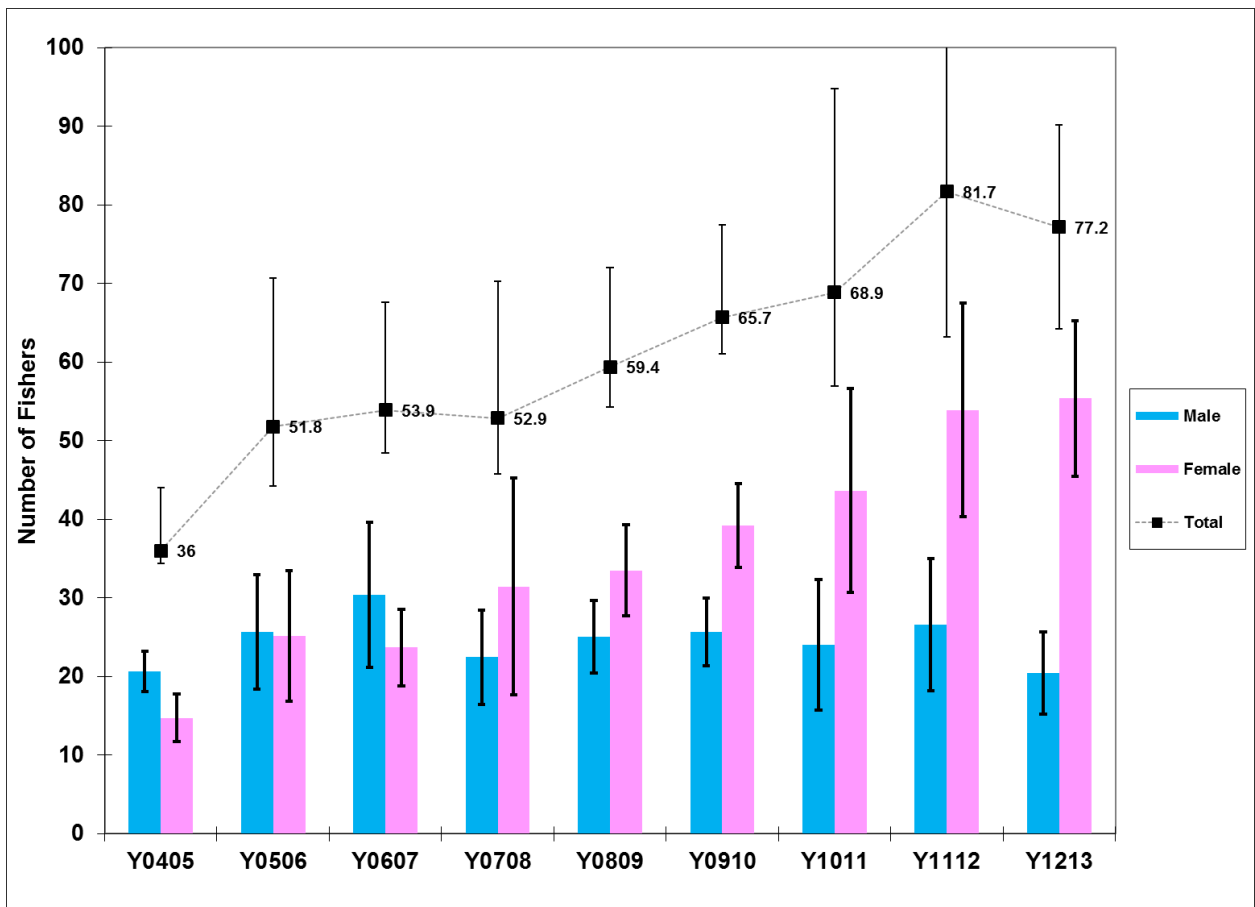
Animal 10006. Drivable Rd  
m/ha = 7.0 Percent of 95%  
FK by Strata type: OPEN =  
5.4, MOF = 49.0 and SX =  
13.3

Animal 10111. Drivable Rd  
m/ha = 8.0 Percent of 95% FK  
by Strata type: OPEN = 7.8,  
MOF = 47.9 and SX = 13.5

**Figure 20 cont. These 4 animals have high estimates of survival. Three of the 4 have died and 1 was censored (10107, collar removed). Of the 3 that have died 2 were from disease and 1 from predation. Average age at time of death was 7.7 years.**



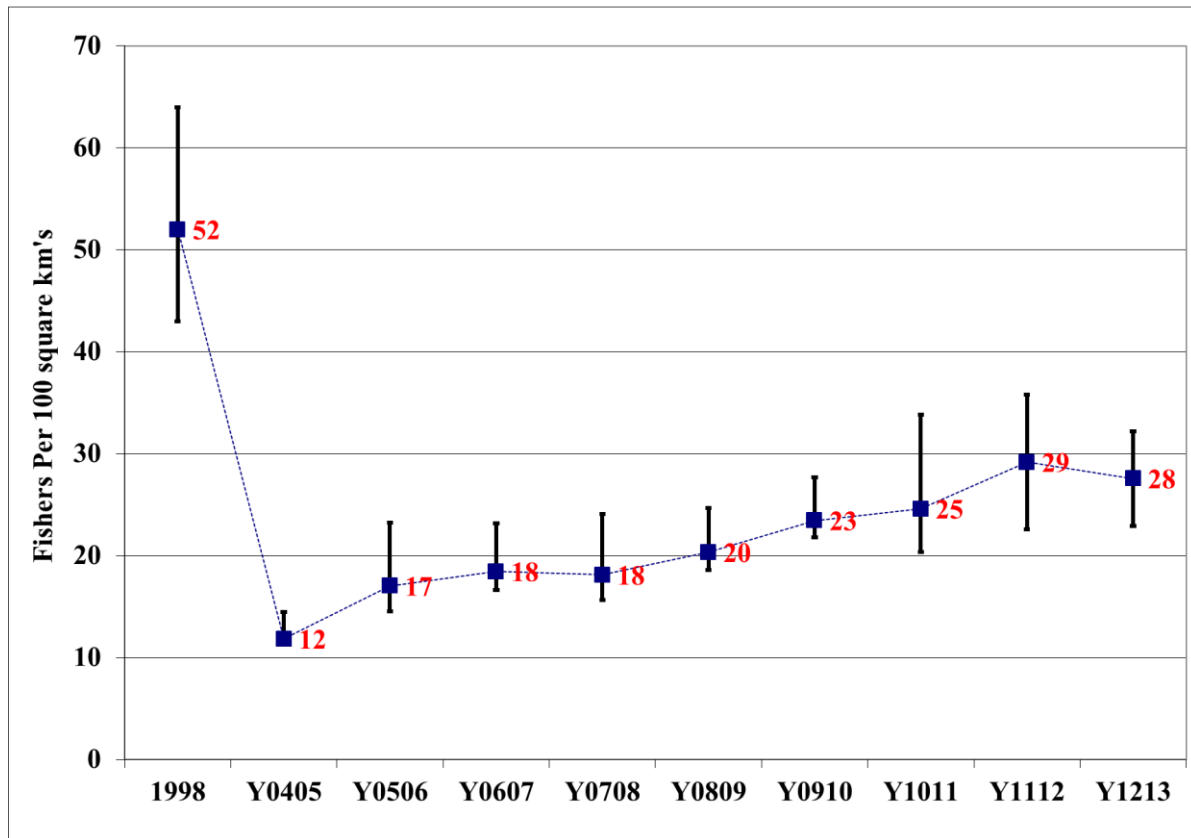
**Figure 19** Total number of female (top) and male (bottom) fishers captured each year and number of first time (new) captures, mean age of all and mean age of new animals with standard error bars, on the Hoopa fisher study area, Humboldt County, CA, 2004-05 to 2011-12 (Age data not available for 2012-13).



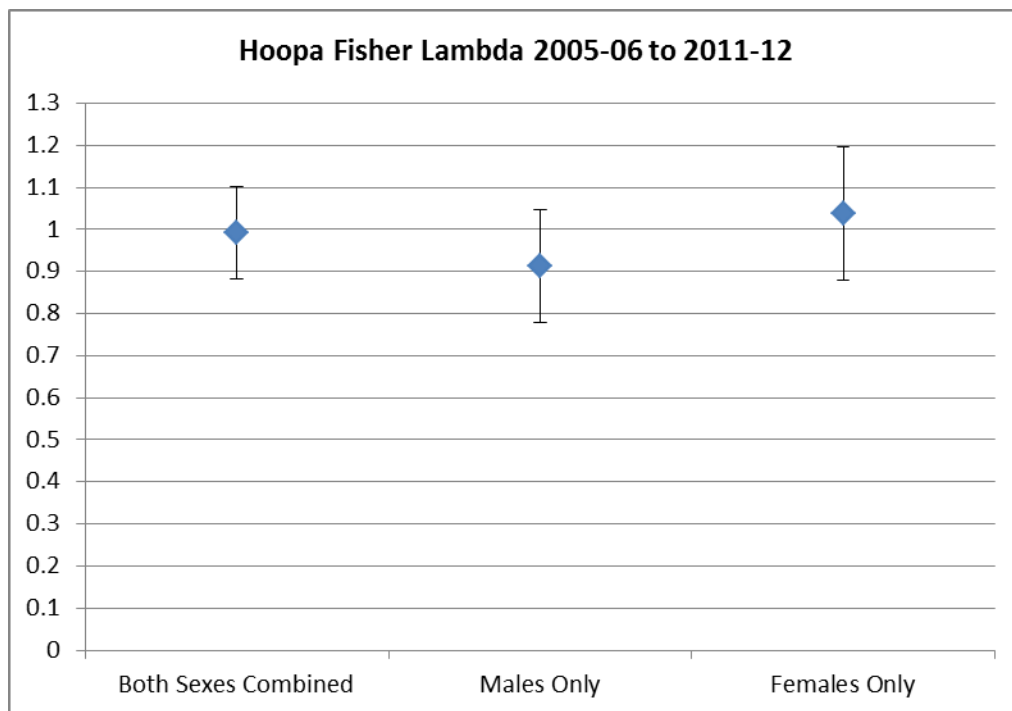
**Figure 20 Annual estimates of the fisher population including male, female and total with 95% CI within the Hoopa Fisher Capture-Mark-Recapture Study Area, 2004-05 to 2012-13, Humboldt County, CA.**



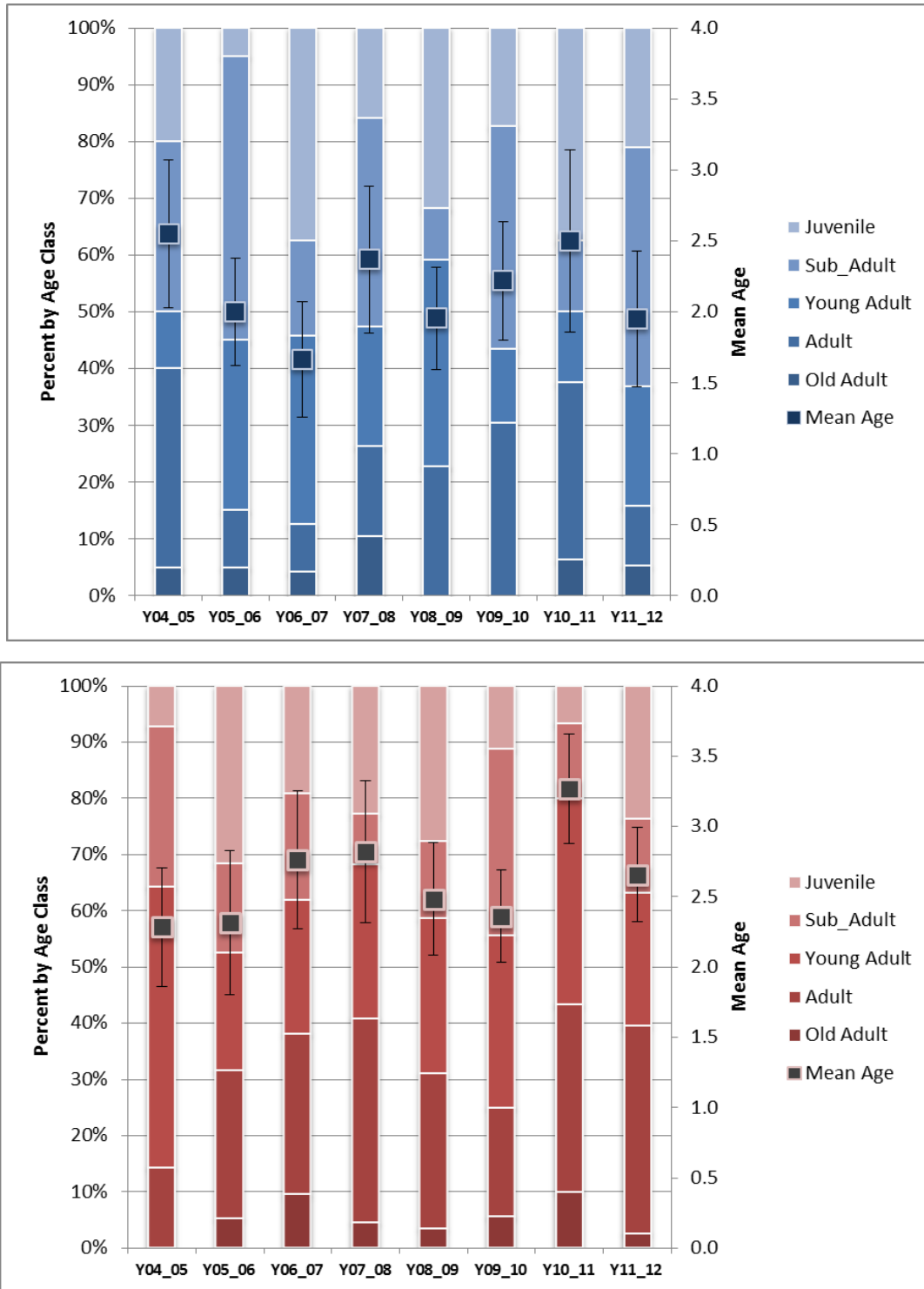




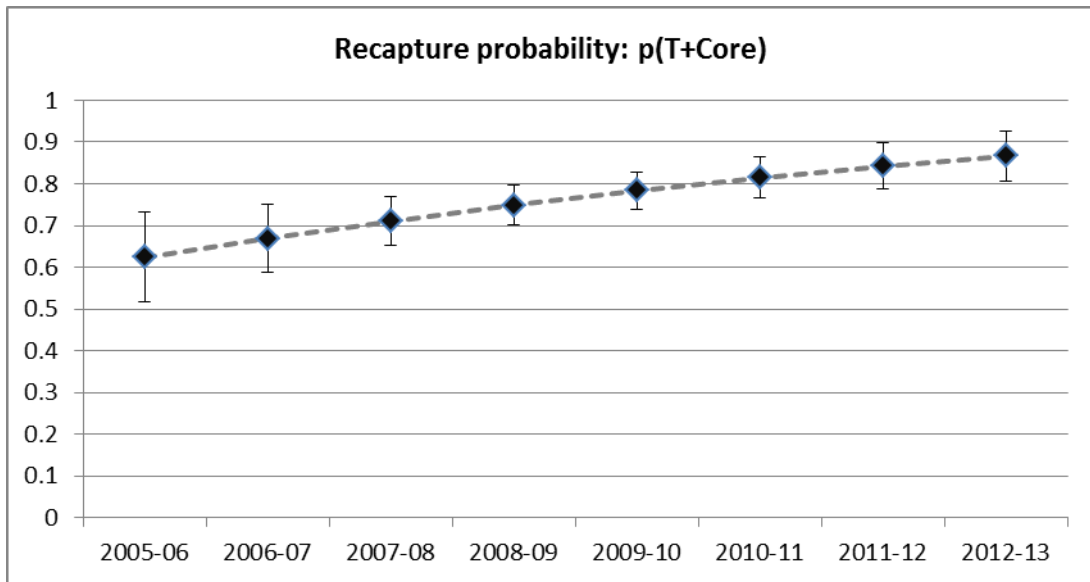
**Figure 21** Fisher population density is gradually recovering following a dramatic decline between 1998 and 2005 on the Hoopa fisher study area, Humboldt County, CA, 2004-05 to 2012-13



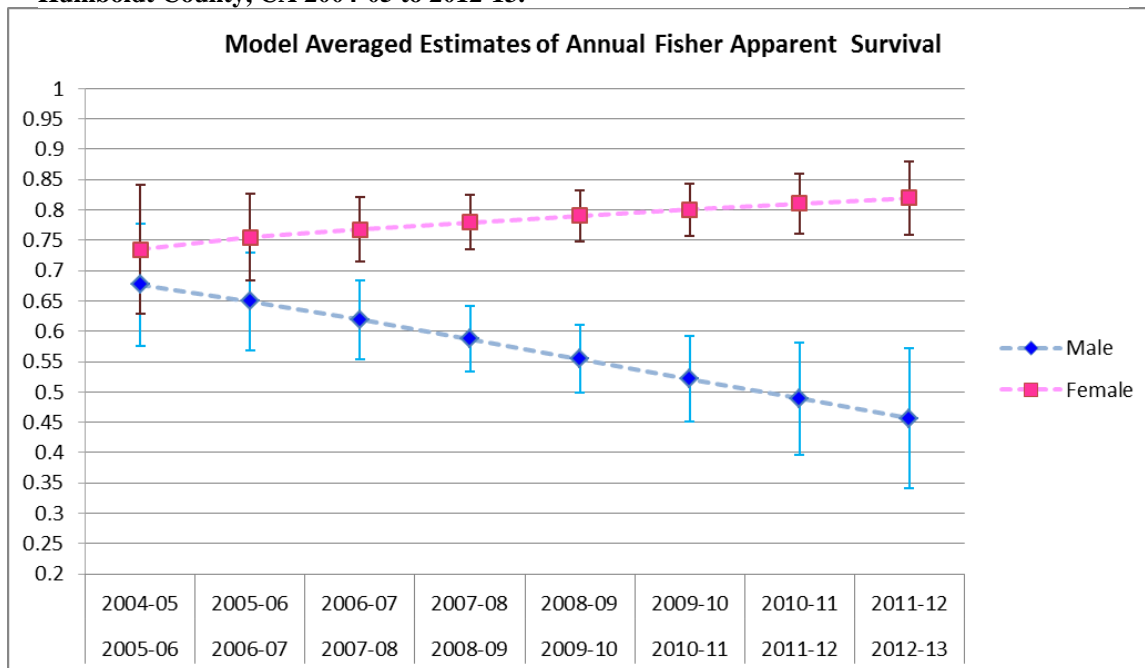
**Figure 22** Figure 24. Fisher Lambda estimates with 95% CI for the population as a whole and males and females separately, Hoopa fisher density study area, Humboldt County, CA, 2005-06 to 2011-12.



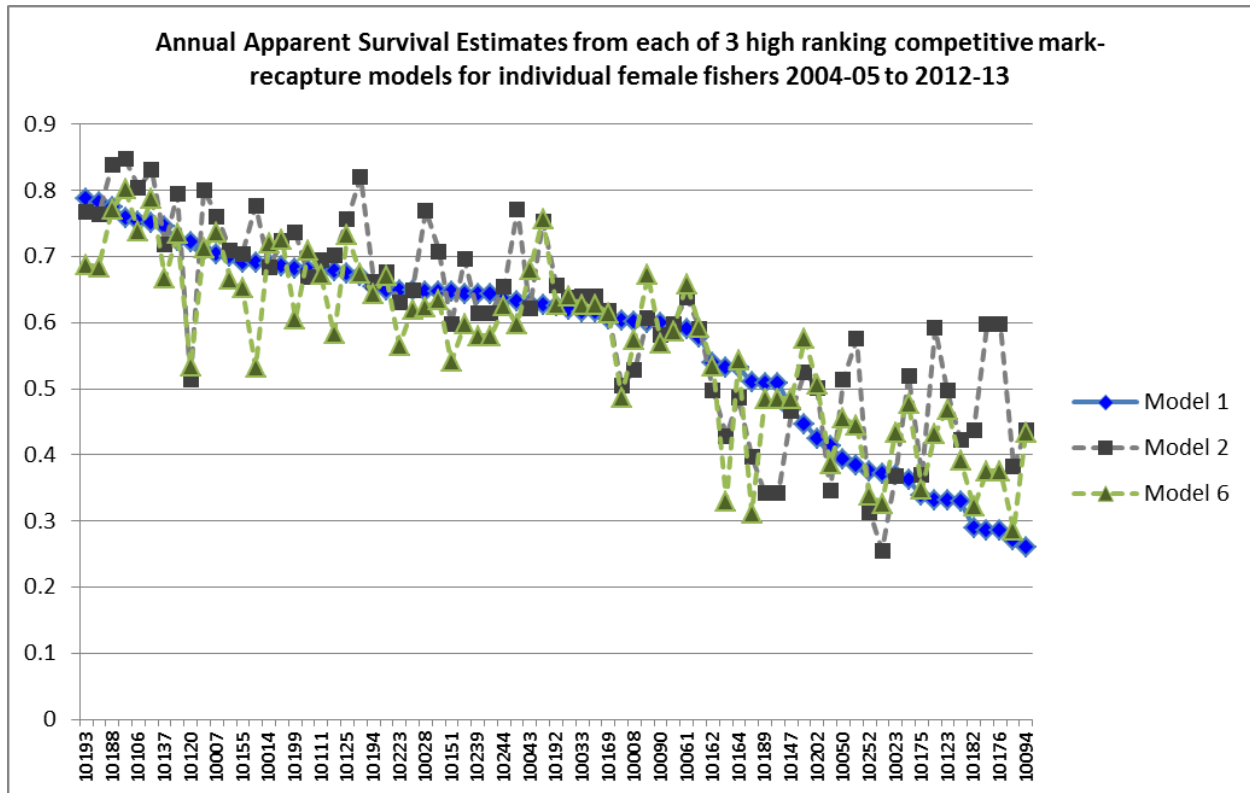
**Figure 23** Male (top) and female (bottom) relative annual age structure for the years 2005-06 to 2011-12. Mean age of females has generally been increasing while males have been shifting up and down. Hoopa fisher study area, Humboldt County, CA.



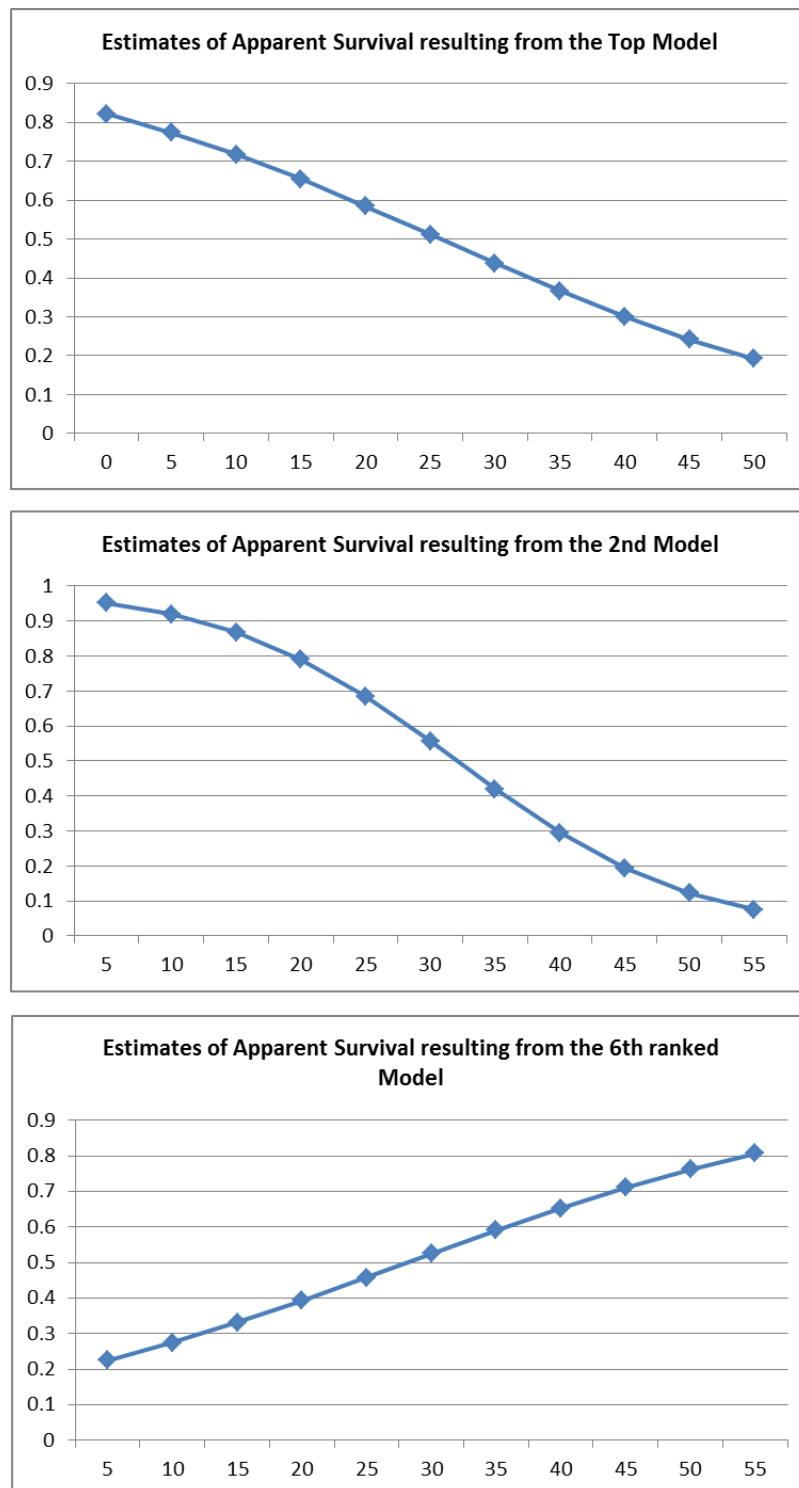
**Figure 24** Annual fisher recapture rates resulting from the best p structure which included an increasing time trend and core-verses fringe trap locations, Hoopa fisher density study area, Humboldt County, CA 2004-05 to 2012-13.



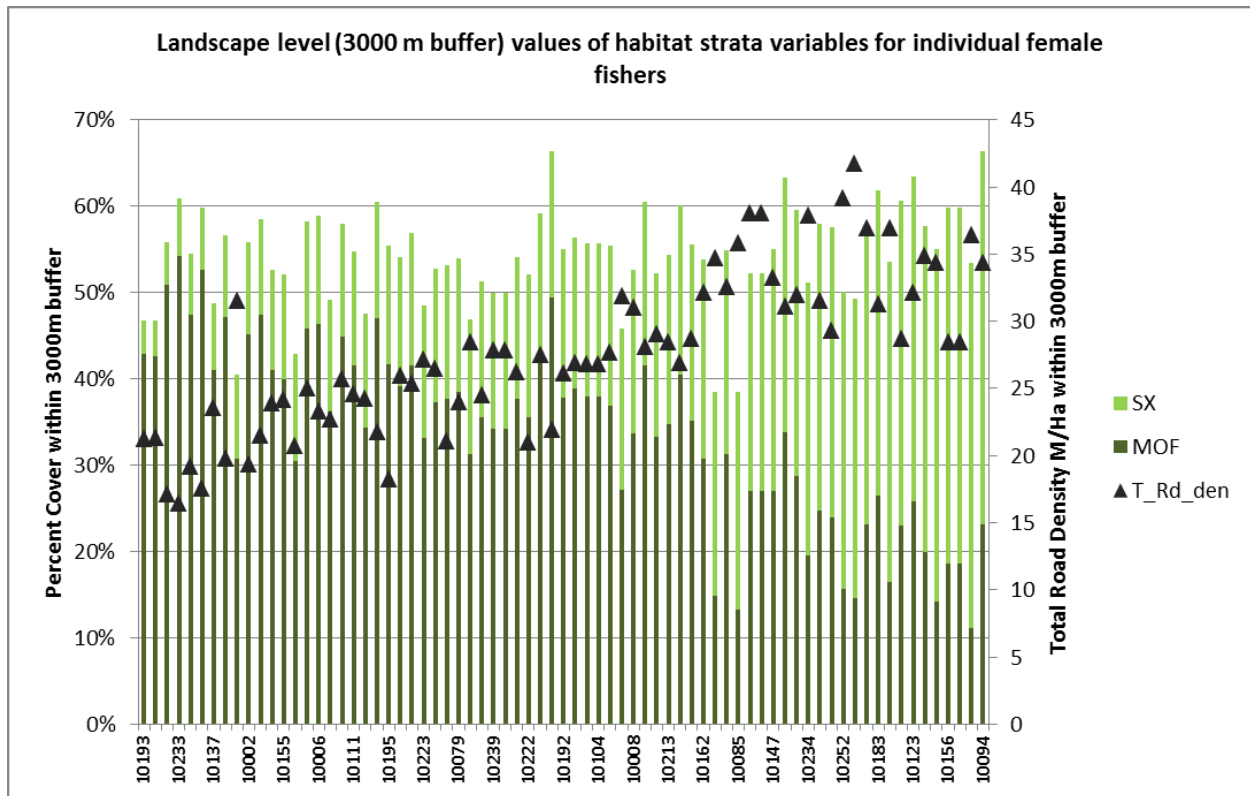
**Figure 25** Annual fisher apparent survival estimates with standard errors resulting from model averaging of several competitive models which indicated differences in male and female apparent survival for the period of 2004-05 to 2012-13 on the Hoopa Valley Indian Reservation, Humboldt County, CA.



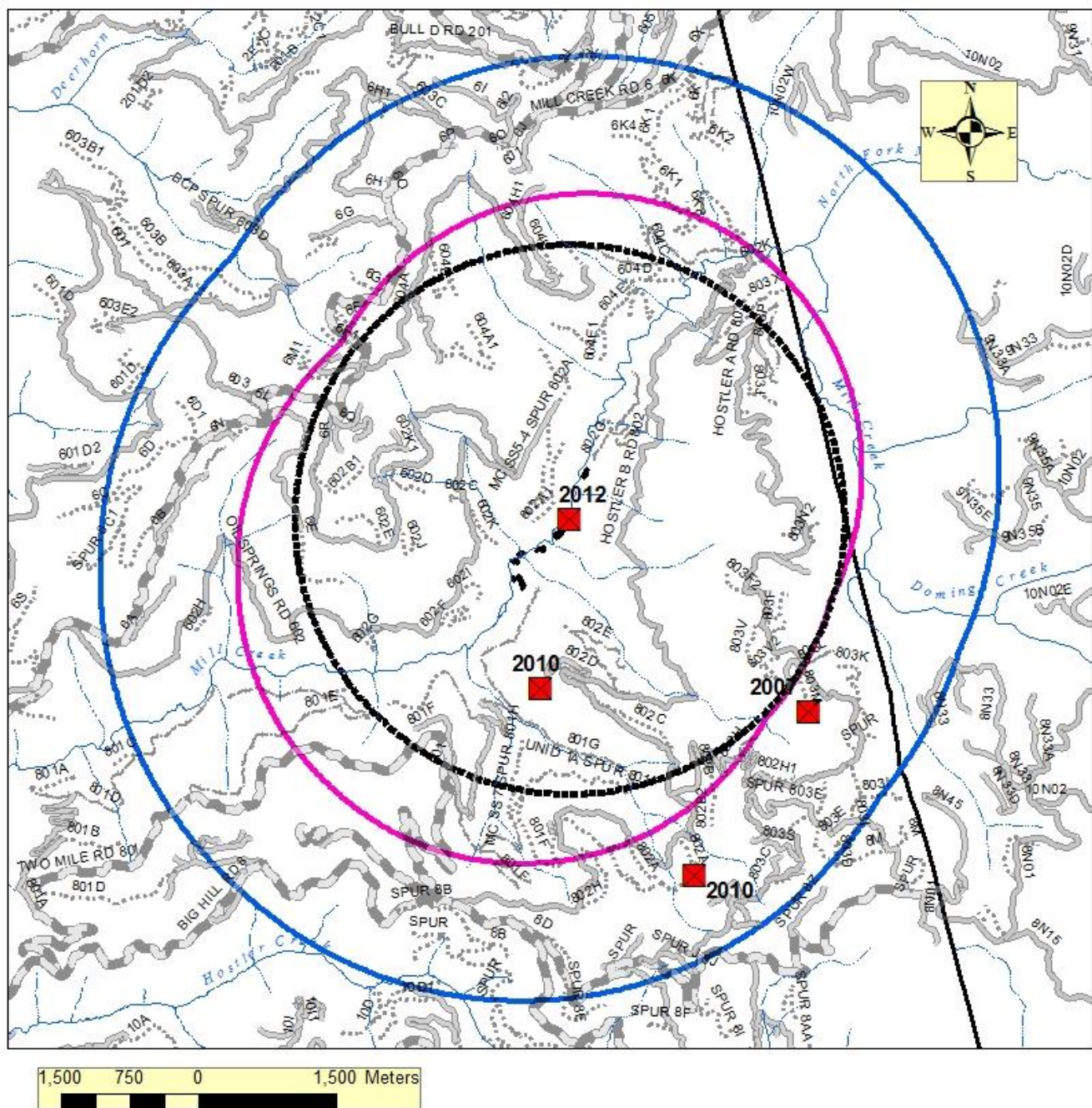
**Figure 26** Estimates of non-juvenile female fisher survival from each of 3 high ranking competitive capture-mark-recapture models which each included different habitat covariates, sorted on the values from the top ranking model. The top model included declining apparent survival with increasing percent cover of stem exclusion strata (SX) within the landscape surrounding the animal's mean center point (3000 meter buffer). The second model included declining apparent survival with an increase in total road density (TotRd) within the landscape while the 6<sup>th</sup> model included an increase in apparent survival with an increase in percent cover of mature and older forest (MOF) within the landscape. Hoopa fisher study area, Humboldt County, CA, 2004-05 to 2012-13.



**Figure 27** Estimates of apparent female fisher survival resulting from three competitive models including habitat covariates. The top ranking model (top) included a negative effect of increasing percent cover of stem exclusion strata (SX) at the landscape scale (3000 meter buffer). The second ranked model (middle) included a negative effect of increasing total road density (TotRd) at the landscape level. Models 3 and 4 also included SX and TotRd but at a smaller scale (1900 meter buffer) while the 5<sup>th</sup> ranked model did not include any habitat covariates. The 6<sup>th</sup> competitive model (within 0.824 QAICc) included an increase in apparent survival with an increase in mature and older forest (MOF). Hoopa fisher study area, Humboldt County, CA, 2004-05 to 2012-13.

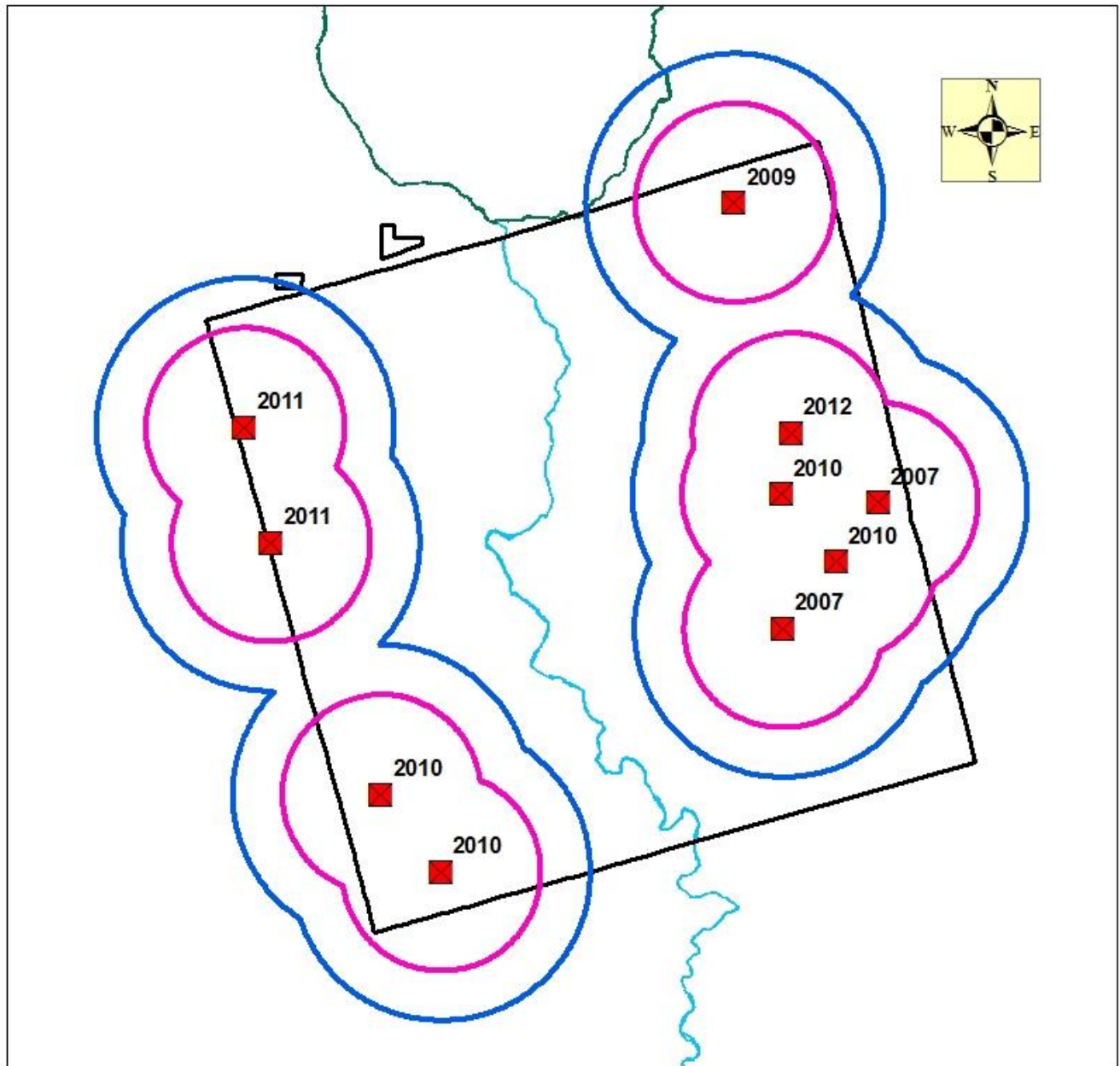


**Figure 28** Percent habitat strata and total road density (meters/ha) within 3000 meter buffers around individual female fisher's mean center points determined from live capture locations. The individuals are sorted by the estimates of annual apparent survival from the top ranked model from highest to lowest from left to right. The top ranked model included a negative effect of increasing percent cover of stem exclusion strata (SX) within the landscape surrounding the females mean center point (3000 m buffer). The second ranked model included a negative effect of increasing total road density (TotRd) within the landscape. The 3<sup>rd</sup> and 4<sup>th</sup> models included the same 2 variables at a smaller scale while the 5<sup>th</sup> model included no habitat strata. The 6<sup>th</sup> competitive model (within 0.824 QAICc) included an increase in apparent survival with an increase in mature and older forest (MOF). Hoopa fisher study area, Humboldt County, CA, 2004-05 to 2012-13.



**Figure 29** Potential zone of impact from anticoagulant rodenticides found at the 2012 Mill Creek illegal marijuana trespass grow (solid black polygons). The dashed black circle represents a 3000 meter buffer around the central point location of the grow site (provided by law enforcement) while the pink and blue outlines represent a 3000 m and 4500 m buffer around the actual polygons. The 3000 m buffer represents the potential zone of impact for female fishers and the 4500m for males based on the mean maximum distance moved for females and males.





**Figure 30** Potential cumulative zone of impact for female (pink) and male (blue) fishers from 10 illegal marijuana grow sites eradicated by law enforcement from 2007 to 2012. Cleanup efforts have occurred at only 1 of the 10 sites and un-opened packages of rodenticide have been found at sites up to 3 years post eradication. Therefore, it is conceivable that sites may remain potential sources of poisons for several years at least.



**Appendix A.** Description of habitat classification that was stratified for use in habitat analysis.

Stand Structural Stages (SSS)	Code	Description
Old Forest Multi-storied	OFM	This stage at Hoopa is the norm for un-harvested stands, but may also include some older cutover stands which retained very significant levels of residual large trees. The large overstory trees form the upper layer and generally there is a mid-story and understory. These stands generally have dense total canopy cover.
Old Forest Single Storied	OFS	This stage at Hoopa is relatively rare in natural occurring stands. It would mostly occur on harsh sites with mixed conifer or true fir stands. It is made up of large and intermediate tree sizes and has no understory and sparse to moderate ground cover.
Young Forest Multistoried	YFM	Young forest begins to differentiate into multiple layers as tree mortality begins to occur in small patches, opening up the overstory canopy and allowing for understory development and excellerating growth of overstory trees near the openings
Understory Re-initiation/sx	UR_sx	One type of older multistoried forest resulting from regeneration harvest with significant overstory retention, uneven age management, or low to moderate intensity fire. In the UR/sx stage the understory has reached stem exclusion stage forming a dense understory canopy and shading out most shade intolerent shrubs and ground cover.
Stem Exclusion/hardwood residual	SX_hd	This was an ad-hoc addition to the strata due to historic logging practices that retained various amounts of large, old hardwoods but no large conifer. These residual hardwoods are very important to some species of wildlife so I included this designation to represent stem exclusion stands that have residual hardwoods but little to no residual conifer.
Stem Exclusion	SX	Young regenerating forest, trees may grow fast initially but slow down as they compete for sunlight, moisture and nutrients. Crowns close and shade out nearly all shade intolerant shrubs
True Oak Woodland	TOW	Nearly pure stands of true oaks with few to no large conifers. Many of these stands now have a vigorous understory of conifers which threaten to overtake and shade out the hardwoods. Some stands will also have madrone and/or tanoak
Understory Re-initiation/sbp	UR_sbp	One type of older multistoried forest resulting from regeneration harvest with significant overstory retention, uneven age management, or low to moderate intensity fire. In the UR/sbp stage the understory and ground cover are dense as the seedlings become saplings and the brush fills inbetween the trees
Stand Initiation/sapling brushy pole	SI_sbp	Young regenerating forest, after stand replacing fire or regneration harvest new seedlings establish and develop into a dense layer of brush and saplings
Understory Re-initiation/seedling	UR_sdl	One type of older, multistoried forest resulting from regeneration harvest with significant overstory retention, uneven age management, or low to moderate intensity fire. In the UR/sdl stage the understory and ground cover are none to moderate as new seedlings establish and develop
Stand Initiation/young pole	SI_yp	Young regenerating forest, after stand replacing fire or regneration harvest new seedlings establish and develop into a dense layer of brush and saplings then the trees overtop the brush and/or stand improvement cuts the brush and the site becomes dominated by trees but not yet closed canopy. Transition from SI to SX type stands
Stand Initiation/seedling	SI_sdl	Young regenerating forest, after stand replacing fire or regneration harvest new seedlings establish and develop
Non-Forested/chaparral-brush	NF_ch	Natural or management related (failed regeneration on serpentine soils) of dense shrub cover with few scattered trees. Generally manzanitta, white thorn, or sometimes hymilaya berries or ceanothes
Non-Forested/Open	NF_open	Natural occuring areas of prairie, meadow or wetland and human altered/converted sites (i.e. urban or agriculture)

Appendix A cont. Mean trees per acre and basal area of overstory, mid-story and understory conifers, hardwoods and total trees within selected stand structural stages (12) . Stand structural stage strata not represented include NF\_Open and SI\_sdl which are both have too few trees and plots to be included.

Strata	# Plots	Conifer						Hardwood						All					
		Overstory		Mid		Under		Overstor y		Mid		Under		Overstory		Mid		Under	
		TP A	B A	TP A	B A	TP A	B A	TP A	B A	TP A	B A	TP A	B A	TP A	B A	TP A	B A	TP A	B A
OFM	117	10	10 5	6	20	16	11	2	11	15	40	119	70	12	11 6	21	60	135	81
OFS	11	27	24 8	11	34	35	23	0	6	1	2	12	6	27	25 4	12	36	47	29
YFM	23	2	18	11	29	66	37	1	5	5	13	124	57 10	3	23	16	42	190	95 13
UR_sx	8	1	7	4	12	64	33	1	6	12	32	200	1	1	13	16	44	264	4 11
SX_hd	37	1	10	3	9	63	29	2	15	13	34	164	88	3	25	16	43	227	7
SX	90	0	3	2	6	76	41	0	3	2	5	136	57 10	1	6	5	11	212	97 11
TOW	9	2	13	1	1	26	13	2	12	7	20	195	2	3	25	8	21	221	5
UR_sb p	4	1	7	3	6			8	64	10	27	66	38	9	71	13	33	66	38
SI_sbp	25			2	4	18	8	1	5	1	3	30	12	1	5	3	7	48	20
SI_yp	11					47	16	0	3	1	3	69	23	0	3	1	3	116	39
UR_sd l	4	5	66	1	5	1	1			1	4	31	23	5	66	3	9	33	25
NF_ch	5	1	6	4	9	47	25					16	6	1	6	4	9	63	31

Overstory = dbh 30+ inches

Mid-Story = dbh 18 to 30 inches

Understory = 6-18 inches

TPA = Number of trees per acre

BA = square feet per acre

Appendix A. cont. Stand structural stages and seral strata used for fisher and bobcat habitat analysis.

Stand Structural Stage (SSS)	SSS_code	Fisher Strata Codes			Bobcat
		SS1	SS4	SS5	Lyrul
Old Forest Multi-storied	OFM	MOF	MOF	FOR	MOF
Old Forest Single Storied	OFS	MOF	MOF	FOR	MOF
Young Forest Multistoried	YFM	YCCFs	YCCF	FOR	YFM
Understory Re-initiation/sx	UR_sx	YCCFs	YCCF	FOR	YFM
Stem Exclusion/hardwood residual	SX_hd	YCCFs	YCCF	FOR	YFM
Stem Exclusion	SX	SX	YCCF	FOR	YCCF
True Oak Woodland	TOW	TOW	YCCF	FOR	TOW
Understory Re-initiation/sbp	UR_sbp	MCOV	OTHER	OTHER	BRUSH
Stand Initiation/sapling brushy pole	SI_sbp	MCOV	OTHER	OTHER	BRUSH
Stand Initiation/young pole	SI_yp	MCOV	OTHER	OTHER	OPSHRB
Understory Re-initiation/seedling	UR_sdl	OPEN	OTHER	OTHER	OPSHRB
Stand Initiation/seedling	SI_sdl	OPEN	OTHER	OTHER	OPSHRB
Non-Forested/chaparral-brush	NF_ch	OPEN	OTHER	OTHER	OPSHRB
Non-Forested/Open	NF_open	OPEN	OTHER	OTHER	OPEN



Appendix A cont. Representative photos from Stem Exclusion stands.



Six photo examples of stem exclusion stands taken in six different stands within the Hoopa fisher study area, Humboldt County, CA. Stem exclusion stands originate with stand replacing events such as intense wild fire or intensive clear cut logging. Once the trees reach a density and height that shades out the understory shrubs and brush they then dominate the site for many years. Often producing no mast as they are struggling to survive fighting for space, sunlight and nutrients. This can lead to very low productivity in this stand type which can last for many years to several decades.