Avian Risk Assessment for South Farallon Islands, California

RISK ASSESSMENT FOR WESTERN GULL EXPOSURE TO THE RODENTICIDES BRODIFACOUM OR DIPHACINONE ON THE SOUTH FARALLON ISLANDS

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EXECUTIVE SUMMARY

The application of bait pellets containing either brodifacoum or diphacinone is being considered along with a range of other techniques to eradicate non-native house mice (*Mus musculus*) from South Farallon Islands (SFI), California. Of particular concern is the risk that these rodenticide products could have to western gulls (*Larus occidentalis*) that occur on the islands. Because western gulls are gregarious omnivores, they could be at risk of exposure via ingestion of bait or exposed mice should the gulls be present on the island when the bait is present. Given this concern, we undertook a probabilistic assessment of the risks posed by the application of bait containing either brodifacoum or diphacinone to western gulls on SFI.

There are three primary techniques for the application of rodent bait on islands for eradication of rodents: bait stations, hand broadcast and aerial broadcast application of bait pellets. The latter is the approach proposed for the South Farallon Islands.

Given the diet and behavior of western gulls and the fate of brodifacoum and diphacinone following bait application, there are two major routes of exposure to gulls: ingestion of rodenticide pellets (primary uptake), and ingestion of rodenticide-contaminated mice (secondary uptake). We used a probabilistic model known as the western gull risk model to estimate the effects of applications of brodifacoum and diphacinone to western gulls at SFI. The exposure portion of the western gull risk model includes both the primary and secondary routes of dietary exposure. The model estimates daily intake of rodenticide from ingestion of pellets and mice for each of 90 days following initial application. The whole body tissue concentration in gulls on any given day is the total daily intake for that day plus the tissue concentration remaining from the previous day. The model runs for a total of 90 days to account for the possibility of two or three applications depending on the rodenticide with an interval of up to several weeks apart. The second and third applications could result in pellets being in the environment for a substantial period of time given that there will be few mice available to consume them. However, by 90 days, a combination of weathering and other factors should have removed all or very nearly all rodenticide pellets from the environment. The exposure metric chosen by the model for comparison to the effects metric is the maximum tissue concentration in gulls during the 90-day simulation.

The western gull risk model determined the theoretical fate (i.e., alive or dead) of 11,000 gulls, which is the peak number of gulls expected on the SFI during the November to March timeframe. Each simulation of the model determines the fate of a western gull. At the outset of a simulation, the characteristics of the gull are randomly chosen (i.e., sex, body weight, life stage). At the same time, the model determines whether the gull will be present on SFI to forage on pellets and/or mice. As a mitigation measure, gull hazing will be implemented as part of the mouse eradication to reduce the number of gulls on SFI immediately following bait application. Thus, the probability of a gull being present is equal to the user selected value for expected

hazing success. Gulls that are not responsive to repeated hazing are assumed to be present each day to forage on SFI.

Based on field data, most gulls will not be present on SFI if initial application occurs in early to mid-November. Thus, for each gull, a starting date for its appearance on the island is determined by the model. Once a gull appears on SFI, it remains in the area until at least mid-February though only unhazed gulls are assumed to forage on the island.

Availability of rodenticide pellets at any given time step is a function of initial availability (i.e., initial application rate) and the rate at which pellets disappear from the environment (e.g., due to consumption by mice, weathering). Subsequent rodenticide applications increase availability of pellets. The probabilities of an unhazed gull consuming pellets and mice over time were calculated using observational data from SFI in 2010. If by random chance pellets and/or mice are consumed at a time step, then the numbers of pellets and/or mice consumed are determined by the model based on the energetic requirements of western gulls and availability of pellets and mice on the island. Primary exposure for each time step is a function of the number of pellets consumed multiplied by rodenticide concentration in each pellet. A similar approach is used for secondary exposure.

The availabilities of pellets and mice change over time in the western gull risk model. Subsequent time steps account for the relative availabilities of pellets and mice by assuming that consumption rates are linearly related to availabilities (i.e., gulls do not increase or decrease their search efforts in response to declining availabilities of pellets and mice). In the case of pellets, availability declines rapidly after the initial rodenticide application because of consumption by mice and weathering if a significant rainfall event occurs shortly after application, and other factors. For subsequent applications, however, pellet availability remains constant until a significant rainfall event occurs which causes the pellets to break down over the next couple of days. In the case of mice, availability declines rapidly from the time they experience symptoms to their death several days to less than two weeks later. After that, mice are not part of the gull diet and thus there is no further secondary exposure.

Gulls learn over time and thus the model assumes conditional probabilities for primary and secondary exposure. That is, if a gull consumes pellets by random chance in the preceding time step, then there is an increased probability of consuming pellets in the subsequent time step. Conversely, if a gull does not consume pellets in the preceding time step, then there is a reduced probability of consuming pellets in the subsequent time step. The same logic is used for gulls consuming mice.

At each daily time step in the model, a tissue concentration is calculated for the gull of interest. The model then searches for the maximum tissue concentration that occurred during the simulation. The maximum tissue concentration is the exposure metric for the gull of interest.

The maximum tissue concentration in each western gull is compared with a randomly chosen gavage dose (in units of mg active ingredient/kg body weight to match the units of the exposure metric) from the dose-response curve for a gull or surrogate species. If the exposure dose for the gull exceeds the randomly chosen effects dose, the bird is considered dead. Otherwise, the bird is assumed to have survived the rodenticide applications. The model then proceeds to simulate the next gull. The process repeats for the number of model simulations selected by the user. The net result over many simulations is that the entire dose-response curve is sampled thus capturing the expected range of sensitivities in the gull population at SFI. Thus, the analysis is not biased conservative, as would be the case with selecting a no observed effect level or low percentile on the dose-response curve (e.g., LD5), nor are potential effects to sensitive birds missed, as would be the case with relying on the LD50.

Model runs were conducted to determine how different application options (e.g., different application dates, differing rates of hazing success, etc.) for brodifacoum and diphacinone affected predictions regarding mortality of western gulls. An analysis conducted by Nur et al. (2012) for western gulls on SFI indicated that a one-time mortality event of 1700 individual gulls would not result in a detectably significant change in the population trend of the western gull on the Farallones over a 20-year period. We compared our model predictions to this benchmark.

It was clear from the modeling analyses that brodifacoum and diphacinone pose similar risks to non-target western gulls. Although diphacinone is markedly less toxic than brodifacoum, gull behavior, the duration that bait would be available, the greater amount of diphacinone bait applied, and the addition of a third application of diphacinone all serve to bring the relative risk posed by the two scenarios modeled closer together. The modeling analyses indicated that an early application date, high hazing success, and an early rainfall event after the last application significantly reduce predicted gull mortality. Assuming an early initial application date (November 1) and hazing success of 90% or higher, neither rodenticide is likely to cause a population-level impact as defined by a gull population viability analysis (PVA) (Nur et al. 2012). The modeling analyses also demonstrated that the primary route of exposure (i.e., consumption of pellets) was, by far, the most important route of exposure for western gulls for both rodenticides. Consequently, to minimize gull mortality, it is recommended that an effective gull hazing program, an early start date, and other measures to reduce gull exposure to bait be investigated.

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1.0 INTRODUCTION

The natural balance and ecology of the South Farallon Islands has been altered due to human presence and the introduction of pest species. Disruption of native biological resources, such as predation of seabirds, has occurred as a result of infestation by non-native house mice (*Mus musculus*). Along with other methods, application of one of two rodenticides, brodifacoum or diphacinone, is being considered to eradicate mice from the South Farallon Islands.

The goals of this assessment were to determine the relative risks of brodifacoum and diphacinone to western gulls (*Larus occidentalis*) and, for each rodenticide, to assist in determining what mitigation measures would be the most effective at reducing risk. Western gulls were the focal species of this risk assessment because it is one of the only resident seabird species of the Farallones that could be present during the proposed mouse eradication period that is not strictly piscivorous. As an omnivore, some western gulls could be at risk of exposure by ingestion of pellets or mice if any gulls are on the island when rodenticide bait is present. The remainder of this chapter provides background information on the South Farallon Islands, the bird species found there, and on the proposed mouse eradication project.

1.1 DESCRIPTION OF THE FARALLON ISLANDS

The Farallon Islands is a group of islands located 28 miles west of San Francisco in the Pacific Ocean. As a declared National Wildlife Refuge, the Farallon Islands are under the jurisdiction of the United States Fish and Wildlife Service (FWS). The surrounding waters are a National Marine Sanctuary and are under the jurisdiction of the National Oceanographic Atmospheric Administration (NOAA). The Farallon Islands, as a group, are also called the "Farallones" which means "rocks out of the sea".

Southeast Farallon Island (SFI) is the largest island in the Farallones group, having an area of 0.31 km² or 310,406 m². The island is pyramidal in shape and is approximately 109 meters above sea level at its peak. SFI is the only inhabited island of the group. The public is no longer allowed access to the islands.

1.2 THE WESTERN GULL (*LARUS OCCIDENTALIS*)

The western gull (*Larus occidentalis*) is a white-headed, medium-sized gull. Like most gulls, the western gull is sexually dimorphic in body size. Adult males measure 60-66 cm in total length, with body mass ranging from 1050-1250 g. Adult females are about 20 percent smaller with a total length of 56-62 cm, and mass of 800-980 g (Pierotti 1981; Pierotti and Annett, 1995). Like most gulls, the western gull is an opportunistic feeder that often forages on live prey (e.g., marine invertebrates, fish, eggs and chicks of other seabird species), scavenges carrion and refuse, and steals food from others.

The western gull is a familiar and well-known species on the Pacific Coast. However, the range and distribution of the species is limited (Pierotti and Annett, 1995). The total worldwide population of western gulls is about 40,000 pairs with 30 percent or more nesting on SFI (Sowls et al., 1980; Penniman et al., 1990). PRBO Conservation Science has been monitoring western gulls and other seabirds and wildlife on the South Farallon Islands daily for over 45 years and this set of data and knowledge, along with that of the FWS Refuge biologists, helped inform many of the parameter estimates of this model.

1.3 PROJECT BACKGROUND

Female mice reach sexual maturity at about 6 weeks and males at about 8 weeks, but both can breed as early as 5 weeks. The reproductive potential of mice is staggering. They have a short gestation period of about 19-21 days. Females can produce 5-10 litters per year ranging in size from 3-12 pups per litter. Thus, a single female can produce between 15 and 168 pups in a single year (Musser and Carleton, 2005). Mice are relatively short-lived with a lifespan of usually less than 1 year in the wild. This short lifespan is often the result of predation and/or harsh environmental conditions.

Rodenticide application is being considered as a potential technique(s) for mouse eradication on SFI. Two registered rodenticides are being proposed for the eradication of mice from the Farallones: brodifacoum and diphacinone. There are three primary techniques of application: bait stations, hand broadcast and aerial broadcast application of bait pellets. The latter is the approach proposed for SFI. Aerial broadcast application would be conducted by helicopter, which is currently the most frequently used bait delivery technique for rodent eradications on large islands (Howald et al., 2007; Parkes et al., 2011). For additional background information on the use of rodenticides to eliminate rodents on islands, see Howald et al. (2007), Witmer et al. (2007), Mackay et al. (2007), Keitt et al. (2011), and Parkes et al. (2011).

As one of the proposed methods of eradication includes the use of a vertebrate toxin, additional assessment is required to determine the degree to which non-target biota could be affected by exposure to brodifacoum or diphacinone. The risks posed by exposure to brodifacoum are expected to be limited for nearly all non-target species (FWS, 2012). Because pinnipeds and most marine birds typically feed exclusively on marine organisms and do not feed while on land, exposure to rodenticides in pellets is unlikely. The likelihood of secondary exposure through consumption of contaminated prey is also expected to be negligible.

However, western gulls would likely be at risk from exposure to a rodenticide due to their omnivorous and aggressive foraging habits. The purpose of this assessment is to assist in estimating the likelihood and magnitude of western gull mortality arising from aerial application of either brodifacoum or diphacinone pellets on SFI. This report is organized to follow the

standard paradigm for ecological risk assessment: problem formulation, exposure assessment, effects assessment, and risk characterization.

2.0 PROBLEM FORMULATION

For this report, the timing of the aerial broadcast of rodenticide was forecast to occur in the late fall or early winter (i.e., November or December). This time of year is when the lowest numbers of non-target species are present on the island. Timing the operation for this period would provide the least risk to the island's native biota. The months of November and December occur after the summer breeding season for seabirds, sea lions, and fur seals and before female northern elephant seals have started giving birth in the early winter (PRBO unpublished data).

There are two general groups of anticoagulants used as rodenticides: the hydroxycoumarins (e.g., warfarin) and the indandiones (e.g., pindone, valone, diphacinone, and chlorophacinone). The second generation anticoagulants (e.g., bromadiolone, brodifacoum, and difethialone) are closely akin to the hydroxycoumarin group (ICWDM, 2005). Second generation anticoagulant rodenticides (SGARs) are much more potent than are first generation anticoagulants, making them effective for rodent eradications (ICWDM, 2005). When formulated at their current concentrations, they have the ability to kill a high percentage of individuals after a single feed. The effects of these compounds are also cumulative and often result in death after several feedings of even small amounts. These properties make SGARs effective primary rodenticides and they have become extremely important for rodent control worldwide (e.g., in New Zealand: Taylor and Thomas, 1989, 1993, Imber et al., 2000; in Canada: Howald, 1997; in the United States: Ebbert et al., 2007, Howald et al., 2009; in Antigua: Daltry, 2006; in Mexico: Samaniego-Herrera et al., 2009). Of the rodenticides, brodifacoum has been the most extensively used for rodent eradication from islands (Howald et al., 2007). Indeed, Parkes et al. (2011) reported that brodifacoum was used in 396 of 546 rodent eradication efforts that were attempted worldwide from 1971 to 2011. Diphacinone was used in 50 of those eradication efforts.

In this chapter, the environmental fate and toxicity of the two rodenticides under consideration, brodifacoum and diphacinone, are briefly reviewed. We then review the foraging behavior and diet of the focal species for this assessment, the western gull, to determine potential routes of exposure. The remainder of the problem formulation describes the assessment and measurement endpoints and analysis plan for the assessment.

2.1 BRODIFACOUM

Brodifacoum elicits acute toxicity by inhibiting the synthesis of vitamin K, which leads to increased coagulation times, followed by lethal internal hemorrhage (Erickson and Urban, 2004). A lethal dose is generally achieved after a single feeding, but mortality is usually delayed for 5 or more days (Erickson and Urban, 2004). Given that, vitamin K also plays a role in bone metabolism (Weber, 2001), studies have been conducted to assess the hypothesis that exposure

of non-target species to sub-lethal concentrations of SGARs may exhibit decreased bone density and bone strength. Such effects place non-target species at risk of bone fractures (Mineau et al., 2005; Knopper et al., 2007) in addition to hemorrhaging.

The high acute toxicity of SGARs and persistence in tissues create the potential for secondary exposure in predatory birds and mammals that feed upon exposed rodents. Erickson and Urban (2004) stated that brodifacoum poses a greater risk to birds and non-target mammals than diphacinone. Mortality incidents have been documented for many non-target predators exposed to brodifacoum (Stone et al., 1999; Howald et al., 1999; Eason et al., 2002; Erickson and Urban, 2004). For example bald eagle (*Haliaeetus leucocephalus*) mortality was recorded on Rat Island in Alaska following the eradication of Norway rats (*R. Norvegicus*). Eagles most likely succumbed on Rat Island after consuming rats or glaucous-winged gull (*Larus glaucescens*) carcasses that had eaten rodent bait containing brodifacoum or, in the case of the gulls, poisoned rats (Salmon and Paul, 2010).

Following application, brodifacoum pellets are either consumed or break down as a result of rainfall, humidity, mechanical grinding and other factors. Once in soil, brodifacoum degrades at rates that vary with soil type (EPA, 1998a). The mechanisms and pathways of brodifacoum degradation in soil are not well described but appear related to moisture, temperature and soil type (Fisher, 2010). The half-life of brodifacoum in soil ranges from 12-25 weeks (EPA, 1998a). In leaching studies, only 2% of brodifacoum added to the soil leached more than 2 cm from its source in the four soil types tested (World Health Organization, 1995; soil type was not defined).

Brodifacoum is highly insoluble in water (Ogilvie et al., 1997). In field studies, freshwater samples were collected and brodifacoum concentrations determined after aerial applications of cereal pellet bait containing 20 mg ai/kg bait. The field studies were conducted at Red Mercury Island (Morgan and Wright, 1996), Lady Alice Island (Ogilvie et al., 1997), Maungatautari, Little Barrier Island and Rangitoto/Motutapu Islands (Fisher et al., 2011). No detectable concentrations of brodifacoum in water were found in any of the studies.

2.2 DIPHACINONE

Diphacinone was first registered for use in the United States in 1960 (EPA, 1998a). It is a first generation indandione anticoagulant, a group that includes other pesticides such as pindone, calone, and chlorophacinone. As a first generation rodenticide, diphacinone is less acutely toxic to birds than are second generation rodenticides such as brodifacoum (EPA, 1998a; Erickson and Urban, 2004; Rattner et al., 2010). Control of rodent populations requires multiple feedings (Ashton et al., 1987). As a result, there is a higher risk of eradication efforts failing with diphacinone than is the case with brodifacoum (Parkes et al., 2011).

Diphacinone is quickly absorbed through the gut of animals, inhibits vitamin K, and uncouples oxidative phosphorylation (EPA, 2011). Studies with birds and mammals have documented increased blood coagulation time, external bleeding, and mortality following consumption of as few as one diphacinone-exposed prey item per day for 3 days (Erickson and Urban, 2004).

Diphacinone pellets or bait blocks can be broken down by rainfall, humidity, weather, mechanical grinding, and other factors. Diphacinone has a low solubility in water of 0.3 mg/L (EPA, 1998a). It has a low potential for volatilization, with a Henry's Law constant of 2×10^{-10} atm-m^3/mol. The potential for leaching is low, but diphacinone is expected to be moderately mobile in soil (EPA, 2011). The half-life of diphacinone in soil is 30 days (EPA, 2011).

2.3 FOCAL SPECIES

The western gull is found predominantly on coastal islands, including major offshore islands, rocky islets, abandoned piers, channel markers, and dikes in commercial salt flats (Pierotti and Annett, 1995). On SFI, gull nests tend to be found in the greatest density on the rocky marine terraces (Pierotti, 1976, 1981). Roosting western gulls can be found on SFI nearly year round, as well as in adjacent offshore waters, but the greatest concentrations occur during the spring and early summer breeding season (April to August) with fewest gulls present in late summer/fall. They are monogamous seabirds with bi-parental care, site and mate fidelity, and a maximum lifespan of 25 years (Pierotti and Annett, 1995). Highest breeding success of western gull pairs is achieved in either rocky or vegetated areas with adequate cover from both weather and predation for semi-precocial young (Pierotti, 1976, 1981). Studies have shown that reproductive success is sensitive to changes in pelagic fish abundance.

Like most gulls, the western gull is an opportunistic scavenger on fish, carrion, and human refuse, and a generalist predator, capturing its own live prey, as well as stealing food from seals and other gulls (Hunt and Butler, 1980; Pierotti, 1976; Annett and Pierotti, 1989; Ainley et al., 1990). They capture food near the water's surface and on shore.

2.4 EXPOSURE ROUTES

Given the diet and behavior of western gulls and the fates of brodifacoum and diphacinone following application, there are two major routes of exposure: ingestion of rodenticide pellets (primary poisoning), and ingestion of rodenticide-contaminated mice (secondary poisoning) (Eason et al., 2002; Erickson and Urban, 2004; Bowie and Ross, 2006). The low solubility of brodifacoum and diphacinone in water precludes significant exposure via drinking water. Dermal exposure will be minimal for western gulls given the non-liquid nature of the pellet formulation, and infrequency of contact (except for ingestion). The nature of the formulation (i.e., pellets) and low vapor pressures for both compounds preclude inhalation exposure.

2.5 PROTECTION GOAL AND ASSESSMENT ENDPOINT

Protection goals are defined by scientific knowledge and societal values, describe the overall aim of a risk-based decision making and are used as the basis for defining assessment endpoints. The protection goal for the SFI mouse eradication project is the long-term maintenance of non-target wildlife species.

Assessment endpoints are ecological characteristics that are deemed important to evaluate and protect. They guide the assessment by providing a basis for assessing potential risks to receptors. Factors considered in selecting assessment endpoints include mode of action, potential exposure pathways, and sensitivity of ecological receptors. Assessment endpoints can be general (e.g., maintenance of bird populations) or specific (e.g., survival of western gulls) but must be relevant to the ecosystem they represent and susceptible to the stressors of concern (Suter et al., 1993). The assessment endpoint for this analysis is the survival of juvenile and adult western gulls following application of rodenticide pelletized bait on SFI.

2.6 MEASUREMENT ENDPOINTS AND ANALYSIS PLAN

Measurement endpoints are the attributes used to quantify potential risks to an assessment endpoint (Suter et al., 1993). The challenge for risk assessors is to select measurement endpoints that will provide sufficient information to evaluate potential risks to the assessment endpoint. EPA (1998b) groups measurement endpoints into three categories. Measures of effect are measurable changes in an attribute of the assessment endpoint, or a surrogate, in response to the stressor (e.g., results of oral gavage studies on birds). Measures of exposure (e.g., daily dose, tissue residues) account for the presence and movement of the stressor in the environment and co-occurrence with the assessment endpoint. Measures of ecosystem and receptor characteristics consider the influence that the environment (e.g., rainfall events), and organism behavior and life history (e.g., diet, timing of nesting) will have on exposure and response to the stressor (EPA, 1998b).

A probabilistic model known as the western gull risk model was used to generate estimates of total intake of rodenticide by western gulls following the applications on SFI. The model included exposure from consumption of pellets and consumption of mice that have consumed pellets. The corresponding measures of effect are dose-response curves for bird species that have been tested for sensitivity to brodifacoum and diphacinone in laboratory exposure tests. The model is described in detail in chapters 3 and 4 of this report.

3.0 EXPOSURE MODEL

We used a probabilistic model known as the western gull risk model to estimate the effects of applications of brodifacoum and diphacinone to western gulls at SFI. The following sections provide an overview of the model, followed by a detailed description of the model inputs and components.

3.1 OVERVIEW OF EXPOSURE MODEL

The exposure portion of the western gull risk model includes both the primary and secondary routes of dietary exposure (Figure 3-1). Once ingested, brodifacoum and diphacinone accumulate and are persistent in tissues of birds, particularly the liver (Erickson and Urban, 2004; Fisher, 2009). The western gull risk model estimates daily intake of rodenticide from ingestion of pellets and mice for each of 90 days following initial application. The whole body tissue concentration on any given day is the total daily intake for that day plus the tissue concentration remaining from the previous day,

$$C_{gull,dayi} = TDI_i + C_{gull,dayi-1} \times RME$$

where C_{gull} is the whole body tissue concentration in mg ai/kg body weight (bw), *TDI* is total daily intake of rodenticide (mg ai/kg bw/day), and *RME* is the daily rate of metabolism and elimination (d^{-1}). The model runs for a total of 90 days to account for the possibility of two or three aerial applications with an interval of up to several weeks apart. The second and third applications could result in pellets being in the environment for a substantial period of time given that there will be few mice available to consume them. However, by 90 days, a combination of weathering and other factors should have removed all or very nearly all rodenticide pellets from the environment (Howald et al., 2001). The exposure metric chosen by the model for comparison to the effects metric is the maximum $C_{gull,\ day\ i}$ estimated during the 90-day simulation. In practice, concentrations in gull tissues stop increasing a few days after the first significant rain event following the last application of rodenticide.

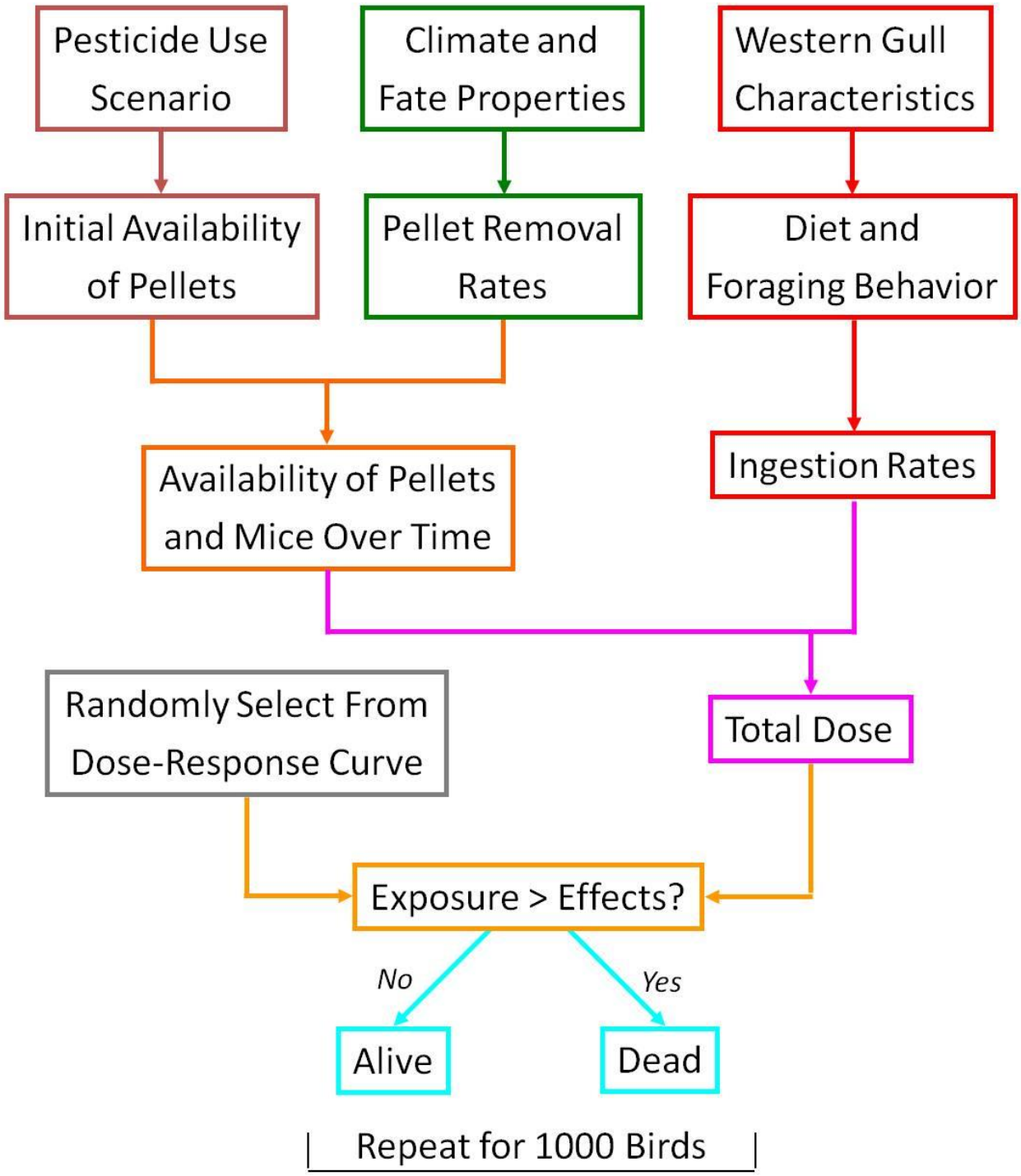

Figure 3-1. Components of western gull risk model for SFI.

The number of western gulls simulated by the model is selected by the user. In the assessment described herein, the number of western gulls included in each simulation was 11,000 gulls which is the peak number of gulls expected on SFI during the November to March timeframe.

See section 3.2.4 for details on how this number was determined. The results are used to determine percent mortality. To determine expected number of dead gulls from applications of rodenticide, percent mortality is multiplied by the maximum number of gulls on SFI in the November to March timeframe, assuming an initial application in the month of November or December).

Each simulation of the model determines the fate of a western gull (Figure 3-1). At the outset of a simulation, the characteristics of the gull are randomly chosen (i.e., sex, body weight, life stage). At the same time, the model determines whether the gull will be present on SFI to forage on pellets and/or mice, based on the expected number of gulls each day over time. As a mitigation measure, gull hazing would be implemented as part of the mouse eradication to reduce the number of gulls on SFI immediately following bait application. Thus, the probability of a gull being present was determined based on the selected value for expected hazing success. The probability of hazing success is entered in a binomial distribution with a sample size of one to determine if the gull will be present to forage by random chance. The model assumes that hazing will occur each day and that gulls responsive to hazing will be absent throughout the 90-day exposure duration. Gulls not responsive to hazing will be present each day to forage on SFI.

Few gulls would be present on SFI if the initial application occurs in early to mid-November, based on PRBO data. Thus, for each gull, a starting date for its appearance on the island must be determined. This is done by randomly selecting from a binomial distribution for each week that has been parameterized with a probability equal to the fraction of the maximum number of gulls present during that time step. Once a gull appears on SFI by random chance, it remains in the area until at least mid-February, though the model assumes that hazed gulls will not forage on the island. The probability of the gull leaving after mid-February is a function of the overall population remaining relative to the maximum number of gulls present on SFI in the fall and winter.

At time zero (day of initial application), pellet availability in the environment is a function of the initial application rate. If a lag time is specified before unhazed gulls begin consuming pellets (data collected at SFI indicate that pellet consumption by gulls is a behavior learned over time), then no consumption takes place on day zero. Similarly, mice are not consumed on day zero because they are not normally part of the western gull diet and are only likely to be consumed once they become easy to capture because of rodenticide intoxication. For brodifacoum and diphacinone, there is a lag time of several days before mice exhibit signs of intoxication (Erickson and Urban, 2004; Fisher et al., 2009). Consumption of pellets and mice can begin at the time steps at which the lag times expire for the primary and secondary routes of exposure assuming that the gull has appeared on SFI (otherwise, there can be no consumption). The number of pellets consumed by an unhazed western gull at the initial time step following expiration of the lag time is a function of availability of pellets and probability of the gull consuming pellets. Availability of pellets at any given time step is a function of initial

availability (i.e., initial application rate) and the rate at which pellets disappear from the environment (e.g., due to consumption by mice, weathering). Subsequent rodenticide applications increase availability of pellets according to the application rate plus pellets remaining from previous applications. The probability of an unhazed gull consuming pellets is a function of observational data from SFI in 2010 in which the proportion of gulls consuming non-toxic pellets was determined (Grout 2012). The observed proportion of unhazed gulls consuming pellets is entered in a binomial distribution with a sample size of one to determine by random chance whether that particular gull consumes pellets on the day at which the lag time for consuming pellets expires. An analogous methodology is used to determine whether the unhazed gull will consume mice following expiration of the lag time for consuming mice. If by random chance pellets and/or mice are consumed at a time step, then the numbers of pellets and/or mice consumed must be determined for the gull of interest. Observational data indicate that once an unhazed gull learns to consume pellets, it may consume many pellets. To determine number of pellets consumed at a given time step, a value is randomly chosen from a Poisson distribution that has been parameterized to ensure that the maximum number of pellets consumed does not exceed the daily energetics requirements of a western gull. Primary exposure for that time step is then a function of the number of pellets randomly selected multiplied by rodenticide concentration in each pellet. A similar approach is used for secondary exposure except that the number of mice consumed cannot exceed the daily energetic requirements of a western gull given the number of pellets already consumed (i.e., model assumes that pellets are a preferred dietary choice over mice). Secondary exposure for that time step is then a function of the number of mice randomly selected multiplied by rodenticide concentration in each mouse. The latter is a randomly chosen value from a lognormal distribution parameterized with measured data from field studies conducted elsewhere. Primary and secondary exposures are summed for each time step to determine total daily intake. As noted above, the tissue concentration in the unhazed gull on any given day is the total daily intake for that day plus the tissue concentration remaining from the previous day.

The availabilities of pellets and mice change over time in the western gull risk model. Subsequent time steps account for the relative availabilities of pellets and mice by assuming that consumption rates are linearly related to availabilities. In the case of pellets, availability declines rapidly after the initial rodenticide application because of consumption by mice, gulls and weathering if a significant rainfall event occurs shortly after application. For subsequent applications, however, pellet availability remains nearly constant until a significant rainfall event occurs. A significant rainfall event causes the pellets to break down over the next couple of days. In the case of mice, availability declines rapidly from the time they experience symptoms to their death several days to less than two weeks later. After that, mice are not part of the gull diet and thus there is no further secondary exposure.

Once the lag times have expired for consumption of pellets and/or mice, the model assumes conditional probabilities for primary and secondary exposure. That is, if a gull consumes pellets by random chance in the preceding time step, then there is an increased probability of consuming pellets in the subsequent time step and vice versa. The same is true for mice. As before, a binomial distribution with a sample size of one is used to determine whether a dietary item is consumed in subsequent time steps. However, the probability entered into the binomial distribution is updated to reflect the conditional probability coefficient. If a dietary item is consumed in a time step, the number of dietary items consumed is randomly selected from a Poisson distribution as before. However, the randomly chosen value from the Poisson distribution is multiplied by relative availability to account for changing availability over time for each dietary item.

At each daily time step in the model, a tissue concentration is calculated for the gull of interest. The model then searches for the maximum tissue concentration that occurred during the simulation. The maximum tissue concentration is the exposure metric for the gull of interest.

The maximum tissue concentration in each western gull is compared with a randomly chosen gavage dose (in units of mg ai/kg bw to match the units of the exposure metric) from the dose-response curve for a gull or surrogate species. If the exposure dose for the gull exceeds the randomly chosen effects dose, the bird is considered dead. Otherwise, the bird is assumed to have survived the rodenticide applications. The model then proceeds to simulate the next gull. The process repeats for the number of model simulations selected by the user.

The input values and distributions for the brodifacoum and diphacinone models are summarized in Table 3-1 and discussed in detail in the subsequent section.

Table 3-1. Input values used in western gull risk models for brodifacoum and diphacinone.

Variable	Value	Units	Source	Notes
Application date	User choice of Nov 1, Nov 8, Nov 15, Nov 22, Nov 29, Dec 6, Dec 13 or Dec 20			
1st application rate (brodifacoum)	18	kg bait/ha	EPA, 2008	Maximum recommended application rates on label.
2nd application rate (brodifacoum)	9			
Number of applications (brodifacoum)	2		EPA, 2008	Label recommends 2 applications to ensure efficacy.
Applications interval (brodifacoum)	12	days	R. Griffiths, pers. comm.	Based on preliminary assessments and previous eradications, interval would likely be 10-14 days.
Brodifacoum concentration	25	mg ai/kg pellet	EPA, 2008	Label states 0.0025% active ingredient in pellet formulation.
Application rate (diphacinone)	48	kg bait/ha	R. Griffiths, pers. comm., based on average rate of bait uptake during 2010 bait trial (Grout, 2012)	Because an uninterrupted supply of this rodent bait is required for up to 21 days to ensure mortality in rats, more applications and a shorter interval between applications will be required to minimize the risk of bait
Number of applications (diphacinone)	3			
Applications interval (diphacinone)	7	days		

Table 3-1. Input values used in western gull risk models for brodifacoum and diphacinone.

Variable	Value	Units	Source	Notes
				being unavailable to mice.
Diphacinone concentration	50	mg ai/kg pellet	Ramik Green Label	Label states 0.005% active ingredient in pellet formulation.
Pellet weight	1.1	g ww	Grout 2012	Mean pellet weight determined from a sample of 100 placebo 3/8-inch diameter pellets.
Pellet half-life (1st application)	1	day	Grout 2012	Nov 2010 trials showed that most pellets from 1st application had disappeared after 5 days. Assuming a half-life of 1 day leaves 3.13% of pellets after 5 days.
Time to significant rainfall event following 2nd application (brodifacoum)	14, 30, or 99	days	Griffiths et al., 2013	Data from Griffiths et al. (2013) indicate that brodifacoum bait takes average of 16, 32, or 101 days to degrade in high, average and drought rainfall years to an unpalatable condition following application. These values were integrated with the "time to removal of bait following significant rainfall event" parameter to model the length of time from application to unpalatability in high, average and drought rainfall years.
Time to significant rainfall event following 2nd application (diphacinone)	96	days	Griffiths et al., 2013	Data from Griffiths et al. (2013) indicate that diphacinone bait takes 98 days to degrade to an unpalatable condition following application. These values were integrated with the "time to removal of bait following significant rainfall event" parameter to model the length of time from application to unpalatability.
Time to removal of bait following significant rainfall event	2	days	Mosher et al., 2007; Howald et al. 2001, 2004; Gregg Howald, pers. obs.	Pellets generally degrade within 2-7 days of a significant rainfall event. There is generally little pellet left to be consumed 2 days after a significant rainfall event. Model assumes lowest value.
Mean brodifacoum concentration in mice	4.9	mg/kg ww	Howald et al., 1999, 2001	Mean of 2.71 mg/kg cited in Howald et al. (2001). Mice were exposed for 4-9 days to 25 mg ai/kg bait. Howald et al. (1999), found mean concentration of 4.9 mg/kg in mice. Assumed underlying lognormal distribution in model.
Standard deviation for brodifacoum concentration in mice	1.26			
Mean diphacinone concentration in mice	51.5	mg/kg ww	Pitt et al., 2011	Tables 1-3 in Pitt et al. (2011) list bait consumption and weights of mice killed by diphacinone-treated pellets (50 mg ai/kg pellet). Upper bound residue concentrations were calculated for each mouse and a mean and standard deviation determined.
Standard deviation (SD) for diphacinone concentration in mice	13.0			

Table 3-1. Input values used in western gull risk models for brodifacoum and diphacinone.

Variable	Value	Units	Source	Notes
				Assumed underlying lognormal distribution in model.
Proportion of gulls removed by hazing	User choice. In this assessment, model runs were conducted for hazing success rates of 75-98%. The baseline rate was 90%. An average hazing success rate of 98% was achieved in the December 2012 trial undertaken on SFI (Warzybok et al. 2013).			
Proportion western gull females	0.5		Pierotti and Annett, 1995	In the south California Bight, sex ratios have been near equity since 1970s and 1980s.
Proportion western gull juveniles	0.46		Nur et al., 2012	There are ~32,200 individuals of which 46% are sub adults and non-breeding adults.
Mean western gull adult body weight (BW) - female	879	g	Pierotti, 1981	Measurements taken on SEFI with sample sizes of 21 and 15 for males and females, respectively. Model assumes underlying normal distribution.
SD of western gull adult BW - female	78			
Mean western gull adult BW - male	1,136			
SD of western gull adult BW - male	47			
Juvenile western gull BW relative to adult body weight	0.875		Penniman et al., 1990	See Table 7.5 in source. Model assumes underlying normal distribution.
Daily probability of gull consuming mice (unhazed gulls)	0.125		Proportion of gulls consuming dead/dosed mice is estimated to vary between 0.01-0.25 (model assumes 0.125) assuming 100% mice availability for unhazed gulls.	
Daily probability of gull consuming pellets (unhazed gulls)	0.25		2010 SEFI field study	Observational and fecal count data indicated an average of 22-25% of unhazed gulls had foraged on pellets. Initial daily rates are much lower, ranging from 0 to 29% during first five days and thus this analysis was conservative.
Conditional probability for consuming mice	0.9		Once birds learn to consume pellets, they will be more likely to consume pellets on subsequent days. No data are available, however, to quantify this behavior.	
Conditional probability for consuming pellets	0.9		Once birds learn to consume pellets, they will be more likely to consume pellets on subsequent days. No data are available, however, to quantify this behavior.	
If mice consumed, Poisson rate	0.2		This value is used as a rate in a Poisson distribution. By adding 1 to the Poisson randomly generated value with a rate of 0.2 suggests an upper limit of 3 mice/gull, which is approximately the maximum value suggested by daily energetic requirements. It is possible for gulls to exceed their daily energetic requirements on any given day, but such a situation is not likely over many days and the great majority of affected mice will be underground.	
If pellets consumed, Poisson rate	15		A Poisson rate of 15 suggests an upper limit of 30 pellets/gull, which is approximately the maximum value suggested by daily energetic requirements. Western gulls foraging on pellets are highly unlikely to eat just one. A rate of 15 would make this outcome unlikely.	

Table 3-1. Input values used in western gull risk models for brodifacoum and diphacinone.

Variable	Value	Units	Source	Notes
Lag time for consuming mice	5	days	Fisher, 2009 (Trial 3 data)	Mice are not normally part of the gull diet on SFI. However, once symptoms of exposure begin (5 days), mice are easier prey.
Lag time for consuming pellets	1	day	Grout, 2012	Trial showed no consumption on day of application but consumption began 1 day later.
Proportion intoxicated mice below ground	0.87		Taylor, 1993; Howald, 1997; Buckalew et al., 2008	Mice generally retreat to burrows following onset of symptoms stemming from exposure to brodifacoum. 87% value was generated from rat data.
Lowest LD50 for brodifacoum	0.26	mg/kg bw	FWS, 2007	LD50 for mallards (EPA, 1998a) used in Rat Island EA (FWS, 2007). This is the lowest LD50 available for birds.
Probit slope for brodifacoum	2.32		Wildlife International, 1979a,b	Values generated from probit regression conducted on raw data for laughing gulls in the reports. Laughing gull should be a reasonable surrogate for western gulls.
Lowest LD50 for diphacinone	0.82	mg/kg bw	Rattner et al., 2012	This value is based on a 7-day dietary study for Eastern screech owls (*Megascops asio*) and represents the lowest lethal dose for mortality. No higher doses/concentrations were tested. Thus, this value is highly conservative.
Probit slope for diphacinone	6.69		Rattner et al., 2010	Values generated from log-probit regression conducted by study authors for most sensitive species tested to date, the American kestrel (*Falco sparverius*).
Half-life for elimination from bird- brodifacoum	217	days	Erickson and Urban, 2004	Calculated mean retention time in the liver from available studies.
Half-life for elimination from bird - diphacinone	7.8	days	Rattner et al., 2011	Half-life for American kestrels.

3.2 DETAILED DESCRIPTION OF EXPOSURE MODEL INPUTS AND COMPONENTS

There are a large number of input parameters in the western gull risk model. In general, variables of minor importance and/or that have little uncertainty and variability were treated as deterministic variables (i.e., one value per variable). Those variables that are variable or have high uncertainty were either treated as distributions or considered in the sensitivity analysis to determine their importance to model predictions. Each of the model input parameters for the western gull risk model are discussed below (also see Table 3-1).

3.2.1 Application of Rodenticide

For brodifacoum, the model assumes two applications on SFI in November-December. The first application rate will likely be 18 kg bait/ha, the maximum rate allowed on the Brodifacoum 25-D label (EPA, 2008). The second application will likely be at a rate of 9 kg bait/ha, which is also the maximum rate allowed on the label (EPA, 2008). The Brodifacoum 25-D formulation consists of grain-based pellets that weigh 1.1 g on average and have a target brodifacoum concentration of 25 mg ai/kg pellet (i.e., 0.0025% active ingredient in the formulation). The interval between applications was assumed to be 12 days.

For diphacinone, the model assumes three applications on SFI in November-December, with an application rate for each application of 48 kg bait/ha. The diphacinone formulation consists of grain-based pellets that weigh 1.1 g on average and have a target diphacinone concentration of 50 mg ai/kg pellet (i.e., 0.005% active ingredient in the formulation). The planned interval between applications is 7 days.

3.2.2 Date of Initial Application

Bird counts in previous years on SFI indicate that western gulls occur in low numbers in early November and increase gradually to peak winter numbers in early to mid-December. The number of gulls on SFI declines slightly beginning in February. Given this information, date of initial application could influence the number of affected gulls because fewer gulls will be present for the initial application if it takes place in early November. To explore the influence of date of initial application, separate model runs were conducted for each rodenticide assuming initial application dates of November 1, 8, 15, 22, and 29, and December 6, 13 and 20.

3.2.3 Removal of Pellets

Generally, cereal-based pellets disappear rapidly from the environment due to degradation from rainfall, humidity, etc. and from consumption by target organisms, i.e., mice in the case of SFI (Buckelew et al., 2005). Trials conducted at SFI in November 2010 demonstrated that non-toxic pellets (i.e., pellets without rodenticide) disappeared in 3-5 days after the first application (Grout, 2012). Such a range suggests a pellet half-life following the first application of 1 day. Near total removal of pellets within a few days has also been observed on other islands with high densities of rodents (e.g., Round Island, Merton, 1987; Anacapa Island, Howald et al., 2001; Gough Island, Wanless et al., 2009). Thus, a half-life of 1 day for removal of pellets following initial application was assumed in this assessment.

Mice are not expected to be present in significant numbers at the time of the second application of brodifacoum or third application of diphacinone. As a result, the likely major removal mechanism for pellets from the SFI environment following the final rodenticide applications will be disintegration following a significant rainfall event (Howald et al., 2001; Gregg Howald, pers. comm.). A significant rainfall event is one sufficient to initiate pellet degradation, which

according to manufacturer and applicator experience, was defined as at least 2 inches (5 cm) of rain occurring over a period of 1-3 days. Merton (1987) previously observed that pellet effectiveness is eliminated with rainfall events of 4 cm (1.6 in) or greater. Daily rainfall data have been collected at SFI since 1972. Thus, high rainfall, average rainfall and drought years were modeled for brodifacoum, and a minimum rainfall period was modeled for diphacinone. Based on data compiled by Griffiths et al. (2013), it is expected that brodifacoum bait will take 16, 32, or 101 days to degrade to unpalatable conditions following its application in high, average, and drought rainfall years. For diphacinone, only a minimum rainfall value of 98 days was available and modeled. Because data were not available for the degradation of diphacinone bait in high and average rainfall years, this parameter is conservative. Because the western gull risk model only simulates the first 90 days after initial application, the analyses for diphacinone and drought years for brodifacoum essentially assume no removal of pellets following the second and/or third applications for the duration of the simulations.

A significant rainfall event will not lead to immediate disintegration of rodenticide pellets. Based on observations of pellets during the SEFI trials in November 2010, Dan Grout of Island Conservation cited a range of 2-7 days for removal of pellets via disintegration following a significant rainfall event (see also Moser et al., 2007; Howald et al., 2001, 2004). Howald et al. (2004) showed that 2 g brodifacoum pellets (dry formulation) were disintegrating within 3 days when there was 1 inch of rain per day. Even with small rainfall events, much of the annual vegetation growth on SFI likely would obscure many if not most bait pellets, which would further limit rodenticide exposure for gulls. In our analyses we used the 2-day value for time to removal of pellets following a significant rainfall event.

3.2.4 Number, Sex and Life Stage of Western Gulls on SFI

The western gull has a total worldwide breeding population of approximately 40,000 pairs of which more than 30% occur on SFI (Penniman et al., 1990; Pierotti and Annett, 1995). Ainley and Lewis (1974) similarly estimated that there are 25,000 individuals present on SFI, of which about 20,000-22,000 of these birds are breeders. The remaining gulls are excess adults because of a lack of nesting areas. Numbers are lowest, perhaps a few thousand birds, during early fall. The numbers increase during November and reach peak numbers in the spring (Ainley and Lewis, 1974).

The number of western gulls on SFI is variable, both seasonally and between years. Observational data collected in November to March 2010-11 and 2011-12 were used to estimate numbers of western gulls on SFI on a weekly basis (Table 3-2). For the western gull model, the two years of data were combined and approximate values generated for each two week period from November to March. These data were used to determine probabilities of a given bird being present (i.e., Model Assigned Value in Table 3-2/Maximum Possible Value of 11,000 birds) for each week through November to March assuming that once a bird appears on SFI in November or December, it does not leave until mid-February at the earliest. A bird can be present but not

foraging on SFI, as would be the case with birds that are successfully hazed each day. The general pattern indicates that the probability of a given bird being present in early November is relatively low and then increases to a probability of 1 by mid-December (Table 3-3). The probability of the bird being present on SFI begins to decline in mid-February (Table 3-3).

Table 3-2. Western gull counts on SFI in 2010-11 and 2011-12.

Month	Day	Mean Gull Count		Two-Year Mean	Two-Week Average	Model Assigned Value
		2010-11	2011-12			
Nov	0	2080.25		2080	2333	2300
	6	2584.75		2585		
	13	1265.14		1265	2317	
	20	1206.5	5530	3368		
Dec	27	2873	5486.67	4180	6948	7000
	34	6716.67	12,716.25	9716		
	41	7402.43	13410	10,406	11,480	11,000
	48	11,074.38	14,034.29	12,554		
Jan	55	12,914.5	14198	13,556	12,114	
	62	10,669.2	10,673.33	10,671		
	69	10,960	8546.67	9753	10,448	
	76	12,500.67	9782.86	11,142		
Feb	83	12,420	8182.857	10,301	10,391	
	90	10,070.29	10,890.5	10,480		
	97	7405.67	4770	6088	5441	8500
	104	6818.67	2770	4794		
Mar	111	8787.75	5224	7006	7852	
	118	10,566.17	6830	8698		
	125	12,620.6		12621	12,344	
	132	12,067		12,067		

Table 3-3. Probability of an individual western gull being present on SFI according to initial application date and simulation day.

Day	Initial Application Date							
	Nov 1	Nov 8	Nov 15	Nov 22	Nov 29	Dec 6	Dec 13	Dec 20
0	0.209	0.209	0.209	0.209	0.636	0.636	1	1
7	0.209	0.209	0.209	0.636	0.636	1	1	1
14	0.209	0.209	0.636	0.636	1	1	1	1
21	0.209	0.636	0.636	1	1	1	1	1
28	0.636	0.636	1	1	1	1	1	1
35	0.636	1	1	1	1	1	1	1
42	1	1	1	1	1	1	1	1

Table 3-3. Probability of an individual western gull being present on SFI according to initial application date and simulation day.

Day	Initial Application Date							
	Nov 1	Nov 8	Nov 15	Nov 22	Nov 29	Dec 6	Dec 13	Dec 20
49	1	1	1	1	1	1	1	0.773
56	1	1	1	1	1	1	0.773	0.773
63	1	1	1	1	1	0.773	0.773	0.773
70	1	1	1	1	0.773	0.773	0.773	0.773
77	1	1	1	0.773	0.773	0.773	0.773	0.773
84	1	1	0.773	0.773	0.773	0.773	0.773	0.773

No information was found on the numbers of females and males present on SFI in November and December. In the Southern California Bight, sex ratios have been near equity since chemical companies stopped disposing waste to the Bight in the 1970s and 1980s (Pierotti and Annett, 1995). On SFI, the sex ratio may be skewed slightly in favor of females during the breeding season (Spear, 1988; Pierotti and Annett, 1995). Given the available information and minor importance of the sex ratio variable we assumed a ratio of males to females on SFI in November and December of 50:50.

According to Nur et al. (2012.), the total SFI population of western gulls of all age classes is about 32,200 birds. Of the 32,200 western gulls, about 17,400 are breeding individuals and about 14,800 are immatures and non-breeding adults. Assuming the latter to be immatures, 46% of the western gulls are immatures. No information was available to determine how the percentage of immature gulls varies seasonally. Thus, in the absence of other information, we assumed that 46% of western gulls present on SFI during November to March are immatures.

3.2.5 Size of Western Gulls

Based on measurements taken at SFI, the mean body weight of female western gulls is 879 g (standard deviation=78, n=15) (Pierotti, 1981). The corresponding mean body weight for males is 1,136 g (standard deviation=47, n=21) (Pierotti, 1981). In the western gull risk model, these values were used to parameterize normal distributions for males and females. Immature males and females were assumed to weigh 87.5% of their respective adult counterparts based upon data presented in Table 7.5 of Penniman et al. (1990).

3.2.6 Hazing Success

A number of studies have shown that gull species (i.e., *Larus* sp.) can be prevented from foraging and loafing in areas where their presence is not desired (e.g., airports, landfills) (Curtis et al., 1995; Slate et al., 2000; Chipman et al., 2004). The most common technique is to use non-lethal pyrotechnics (Chipman et al., 2004). This technique can be quite effective and has been observed to remove all or nearly all gulls if used on a daily basis. As such, daily hazing is being

considered as a mitigation measure on SFI to reduce the number of gulls exposed to the rodenticide following application. Although daily hazing has been an effective management tool at airports and landfills, its long-term effectiveness as a tool on SFI can only be inferred from the trials that have been conducted. Thus, in this assessment we conducted model runs for each rodenticide for a range of possible hazing successes, i.e., 75%, 90%, 95% and 98%. An extensive hazing trial was conducted in December 2012 at SFI to evaluate hazing techniques and quantify effective hazing rates in the field over a 2 week period. Hazing efforts were on average 98% effective at keeping gulls off the island and away from areas that would be baited during an eradication effort (Warzybok et al. 2013).

3.2.7 Primary Exposure Route Variables

Cereal grains such as those found in the rodenticide pellet formulation are not found on SFI and thus are not normally part of the diet of western gulls. In general, western gulls are predators that forage on pelagic and intertidal marine fishes and invertebrates (Hunt and Hunt, 1976; Hunt and Butler, 1980; Pierotti, 1980; Ainley et al., 1990; Pierotti and Annett, 1995; Snellen et al., 2007). However, western gulls are opportunistic and will forage on other items that are readily available (Pierotti and Annett, 1995). During the SEFI trials in November, 2010, western gulls were observed feeding on non-toxic pellets. Pellet consumption was infrequent immediately after first application but increased as more gulls became aware of the food source (IC, 2011). Data from the SEFI trials indicated that 22% of unhazed gulls in the bait zone were observed or suspected of foraging on grain pellets. Further, approximately 25% of gull fecal pellets had a green dye that had been incorporated in the pellets. To be conservative, we assumed a 25% daily probability of an unhazed gull consuming at least one pellet when pellets are readily available (i.e., shortly after application). A binomial distribution was assumed for this variable for each day of the model simulation.

In the western gull risk model, consumption of pellets was assumed to decline in direct relation to the decline in availability of pellets relative to the day of initial application. Thus, the daily probability of consuming pellets is adjusted to account for the availability of pellets. For example, if the daily probability of an unhazed gull consuming pellets on day zero is 25% and the availability of pellets on the surface compared to day of initial application is 3.1% on day 5 (the case when the pellet half-life is 1 day), then the daily probability of an unhazed gull consuming pellets on day 5 is 0.73%. Pellet availability increases with subsequent applications of rodenticide.

Observational data at SEFI suggest that once gulls learn of the pellet food source, they are more likely to return to that food source in successive days. We incorporated a conditional probability for daily probability of consuming pellets to account for this learned behavior. Quantitative data to parameterize the conditional probability, however, are lacking. A value of 90% was assigned to this variable. Although we assumed that most gulls, once they ate bait, would eat it again the next day, we assumed a 10% daily turnover rate of western gulls in the fall (a very conservative

estimate). Thus, the probability of a gull consuming pellets on day 1 doing so on day 2 is ~90%. The conditional probability essentially adjusts the daily probability of an unhazed gull consuming pellets given the result from the previous day. Thus, consumption of one or more pellets the previous day increases the probability of consuming one or more pellets the following day (i.e., to 90%). If a gull does not consume any pellets on the previous day, it will be less likely to consume pellets the following day. The higher the conditional probability, the more likely that there will be long strings of days with pellet consumption and long strings of days without pellet consumption. There are no scientific data available from the Farallones or elsewhere upon which to base this 90% input parameter, but it was considered best to conservatively assume a relatively high likelihood of a gull consuming bait on a day subsequent to initial bait consumption. A rate of 90% was considered to be a high end estimate, given the high rate of learned foraging behavior observed in Farallon western gulls. In addition, the daily return rate of western gulls on the Farallones may not be 100%. It is likely a relatively high value, due to lack of extreme daily migratory behavior observed in western gulls, as well as observed movement of banded birds from this population.

In addition to determining whether an unhazed gull feeds on pellets in each day of the model simulation, we need to determine the number of pellets consumed on days when consumption occurs. Observations during the SEFI trials in November, 2010 indicated that when pellets are readily available, unhazed gulls are unlikely to consume just one pellet once consumption begins. To determine the daily maximum number of pellets that could be consumed, we determined the number of pellets required to meet the metabolic needs of adult gulls. The metabolizeable energy in cereal grain baits consumed by birds is 14.0 kJ/g dw bait (Nagy, 1987). Assuming a moisture content of 14% (Nagy, 1987) and a pellet mass of 1.1 g as determined in SEFI field measurements of 100 placebo pellets, the metabolizeable energy in each pellet is 13 kJ/pellet ww. Adult western gulls require approximately 12 (females) to 14 (males) kJ/hour for normal maintenance during the non-breeding season (Pierotti and Annett, 1995). Thus, daily energy requirements are 288 and 336 kJ/day for female and male western gulls, respectively, similar to the values estimated for herring gulls (Pierotti and Annett, 1991; EPA, 1993). The upper bound for pellets consumed per day to meet daily energetic requirements for male western gulls would be 26 (336/13 = 26). We rounded this figure to 30 pellets/day to be conservative and because gulls may consume more food than required to meet typical daily energetic requirements on some days. A Poisson distribution with a rate of 15 for daily number of pellets consumed results in a distribution for which low (e.g., 1-3 pellets/day) and high values (i.e., 28-30 pellets/day) are rare events, but values in between are more common.

Finally, the western gull risk model assumes a 1 day lag time for consuming pellets because the SFI trials in November demonstrated that pellet consumption did not begin until the day after application.

3.2.8 Secondary Exposure Route Variables

Birds have the potential to consume live rodents or carrion containing brodifacoum or diphacinone residues (Eason et al., 2002; Erickson and Urban, 2004; Bowie and Ross, 2006). As with consumption of pellets, the western gull risk model estimated the daily probability of consuming mice and, should consumption occur, the number of mice consumed per day.

Few data are available to determine the daily probability of consuming mice by western gulls. Stomach contents analyses show that consumption of rodents by gulls is low and typically in the range of 0-2% (Ainley et al., 1990; Pierotti and Annett, 1995). However, unhazed gulls are expected to change their behavior following rodenticide application on SFI because intoxicated or dead mice are easier to capture. Scavenging of trapped mice was observed during the SFI trials in November, 2010, with a maximum estimated scavenging rate of 25%, although most of this scavenging was likely done by other mice. Some of the mouse carcasses could have been scavenged by gulls, however, though it is also possible that none of the mouse carcasses were scavenged by gulls (Grout, 2012; Pott and Grout, 2012). Given the range of 0-25% of rodents in the diet of unhazed gulls, we selected an average probability of 12.5% for daily probability of consuming mice when they are intoxicated and readily available. A binomial distribution was assumed for this variable for each day of the model simulation.

The availability of mice for consumption by western gulls declines following exposure to brodifacoum and diphacinone. In a study by Fisher (2009), rats exposed to brodifacoum in their diet showed few symptoms for the first 5 days following initial exposure after which symptoms began to appear. All rats died 6-13 days following initial exposure. Eighty-seven to 100% of rodents generally retreated to burrows to succumb following onset of symptoms stemming from exposure to brodifacoum (Taylor, 1993; Howald, 1997; Buckalew et al., 2008). Similarly, EPA (1998) noted that mice may experience symptoms within 3 days of exposure to diphacinone and die within 9 days of continuous exposure. Dead or dying mice that have retreated to burrows would not be available for consumption by unhazed western gulls on SFI. We used the Trial 3 data from Fisher (2009) and the worst case value of 87% for mice retreating to burrows to estimate the proportion of the mouse population available for consumption on SFI as a fraction of pre-exposure abundance. Based on data from Fisher (2009), symptoms were assumed to precede death by 2 days. The fitted regression model for the worst case scenario is shown in Figure 3-2. In the western gull risk model, once mice are dead, they are no longer available. Intoxicated mice on the surface, however, are available for consumption. The regression model for the worst case scenario is:

$$y = 0.0116x^2 - 0.215x + 1 \ (worst\,case)$$

Model fit for the worst case scenario was excellent with a correlation coefficient of 0.99. Thus, we have high confidence in the parameterization of the regression model. In the western gull risk model, consumption of mice was assumed to decline in direct relation to the decline in

availability of mice relative to pre-application conditions. Thus, the daily probability of an unhazed gull consuming mice is adjusted to account for the availability of mice compared to pre-exposure. For example, if the daily probability of an unhazed gull consuming mice on day zero is 12.5% and the availability of mice on the surface compared to pre-exposure is 79.7% on day 5, then the daily probability of consuming mice on day 5 is 9.96% (i.e., 12.5% x 79.7% = 9.96%).

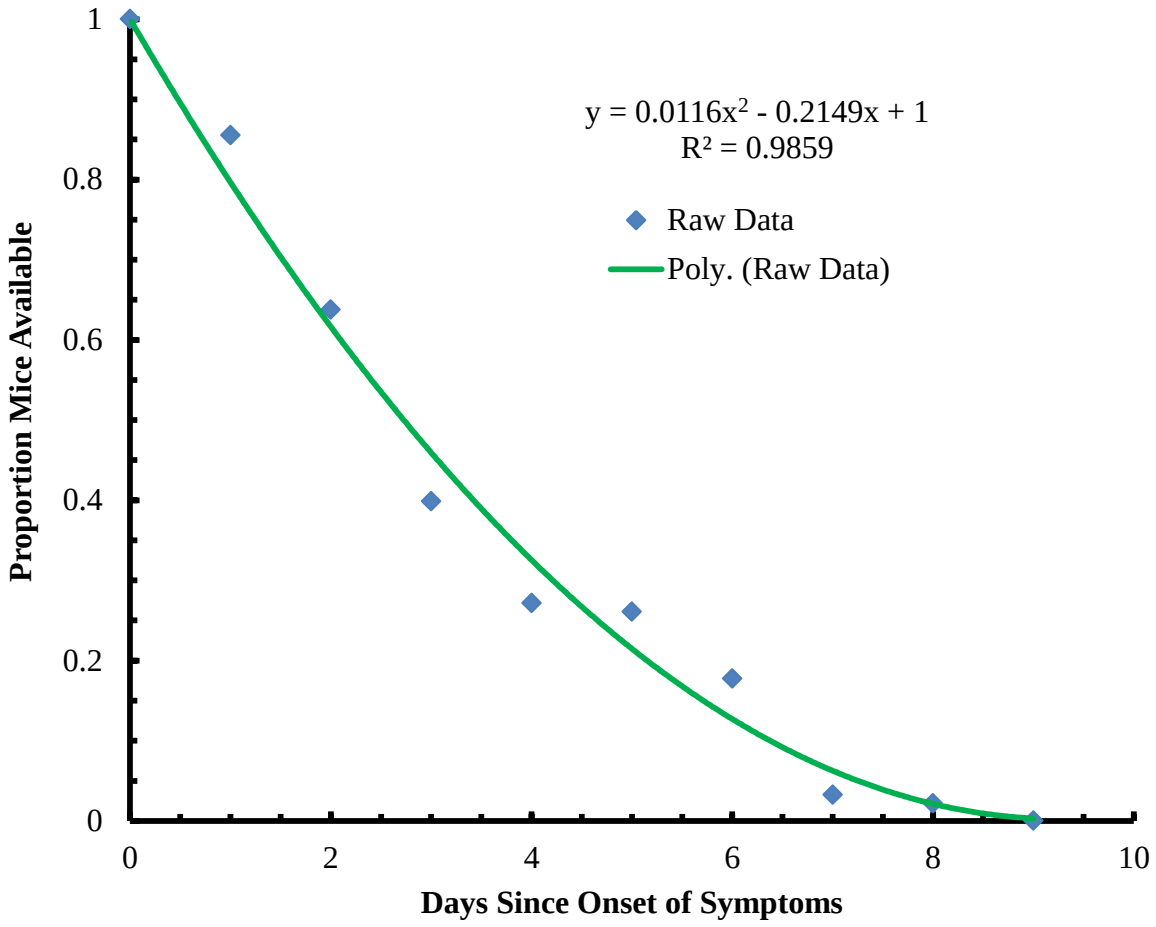

Figure 3-2. Proportion of mice available for consumption by western gulls following application of brodifacoum on SFI. Raw data are from Fisher (2009). The fitted model is a 2nd order polynomial model. Symptoms begin 5 days after initial application with death following 2 days after onset of symptoms.

As with pellets, once unhazed western gulls are aware of intoxicated mice as an easy food source, they are more likely to return to that food source on successive days. We incorporated a conditional probability for daily probability of consuming mice to account for this learned behavior. Quantitative data to parameterize the conditional probability, however, are lacking. As with pellets, we assumed a conditional probability of 90% for mice based on discussions with

Dan Grout from Island Conservation. The conditional probability essentially adjusts the daily probability of an unhazed gull consuming mice given the result from the previous day.

In addition to determining whether an unhazed gull feeds on mice in each day of the model simulation, we need to determine the number of mice consumed on days when consumption occurs. We determined the number of mice required to meet the metabolic needs of adult gulls. The gross energy of mice is 8.4 kJ/g ww and they are assimilated by birds with an efficiency of 78% (EPA, 1993). Thus, the metabolizeable energy of mice is 6.55 kJ/g ww. Assuming an average body weight of 15.5 g for the house mouse (calculated from 278 samples during 2010 SFI field trials), the metabolizeable energy of each mouse is 102 kJ/mouse. Adult western gulls require approximately 288 and 336 kJ/day for female and male western gulls, respectively (Pierotti and Annett, 1991; EPA, 1993). Thus, the upper bound for mice consumed per day to meet daily energetic requirements for male western gulls would be 3 (336/102 ≈ 3). By adding 1 to a value drawn randomly from a Poisson distribution with a rate of 0.2 generates an upper bound of 3 mice/gull/day. It is possible for gulls to exceed their daily energetic requirements on any given day but such a situation is not likely, on average, over many days and the likelihood of such an event will be further diminished by the majority of mice dying underground.

Unhazed gulls could conceivably ingest both pellets and mice on the same day. To ensure that the model does not allow for exceedance of daily energetic requirements, the number of mice that could be consumed daily was limited to 0 if number of pellets consumed daily was >25, 1 if number of pellets consumed daily was >15-25, 2 if number of pellets consumed daily was >5-15, and 3 if number of pellets consumed daily was 5 or less.

To determine rodenticide concentration in unhazed gulls via consumption of mice requires data on expected concentration in mice. For brodifacoum, Howald et al. (2001) cite a mean concentration in mice exposed for 4-9 days to 25 mg ai/kg bait (i.e., same concentration as Brodifacoum-25D) of 2.71 mg ai/kg ww (standard deviation=0.7). Howald et al. (1999), however, cite a mean concentration of 4.9 mg ai/kg ww in exposed mice. We selected the worst case mean concentration in mice of 4.9 mg ai/kg ww. The coefficient of variation (CV) determined in the Howald et al. (2001) study (CV = 0.7/2.71 x 100 = 25.8%) was used to derive the standard deviation of 1.26 for the worst case scenario. Concentrations in mice were assumed not to change over time given the persistence of brodifacoum in tissues (Erickson and Urban, 2004) and the short period of time that mice remain after initial rodenticide application. For each mouse consumed in the brodifacoum model, a value was randomly chosen from a lognormal distribution parameterized with the mean concentration and associated standard deviation.

Little information is available on concentrations of diphacinone in mice following exposure to bait. Pitt et al. (2011) exposed mice to diphacinone in pellets at the same concentration as proposed for SFI (i.e., 50 mg ai/kg bait). Although the authors did not measure the resulting concentrations of diphacinone, they did determine mouse body weights and pellet ingestion rates

in six mice that died during the course of the study (see Tables 1-3 in Pitt et al., 2011). Assuming that the mice did not metabolize or eliminate any of the ingested diphacinone, a worst case assumption, the resulting mean concentration in mice was 51.5 mg ai/kg bw. The corresponding standard deviation was 13.0. As with brodifacoum, diphacinone concentrations in mice were assumed not to change over time given the persistence of this pesticide in tissues (Erickson and Urban, 2004) and the short period of time that mice remain after rodenticide application. For each mouse included in the diphacinone model, a value was randomly chosen from a lognormal distribution parameterized with the mean concentration and associated standard deviation.

The western gull risk model assumes a 5 day lag time for consuming brodifacoum-contaminated mice because this is the length of time required for mice to become intoxicated and thus easily captured (Fisher, 2009). The corresponding value for diphacinone is 3 days (EPA, 1998).

We incorporated the rates of metabolism and elimination of brodifacoum and diphacinone in the western gull model because of the length of the model runs (i.e., 90 days following initial application). Erickson and Urban (2004) reviewed the available literature for birds and determined a tissue half-life of 217 days for brodifacoum. Assuming first-order kinetics, the resulting fraction of brodifacoum retained in gull tissues on a daily basis is 0.997. For diphacinone, Rattner et al. (2011) determined a half-life of 7.8 days in American kestrels. Assuming first-order kinetics, the resulting fraction of diphacinone retained in gull tissues on a daily basis is 0.915.

4.0 EFFECTS CHARACTERIZATION

In this chapter, we derive effects metrics (i.e., dose-response curves) for gulls or surrogate species exposed to brodifacoum and diphacinone. The chapter concludes with a discussion of the pros and cons of using effects metrics from oral gavage studies versus dietary studies.

4.1 EFFECTS METRICS FOR BRODIFACOUM

The available information on the acute toxicity of brodifacoum to various bird species is summarized in Table 4-1. Avian LD50s range over nearly two orders of magnitude from 0.26 mg ai/kg bw for the mallard (*Anas platyrhynchos*) to 20 mg ai/kg bw for the Paradise shelduck (*Tadorna variegata*). By comparison, Erickson and Urban (2004) noted that the warfarin LD50 for the mallard is 620 mg ai/kg bw.

Table 4-1. Acute toxicity of brodifacoum to avian species (modified from Erickson and Urban, 2004; Godfrey, 1985; Eason et al., 2002; Bowie and Ross, 2006).

Species	LD50 (mg ai/kg bw)	Reference
Mallard	0.26	EPA, 1998a
Canada goose	<0.75[a]	Godfrey, 1986
Southern black-backed gull	<0.75[a]	
Purple gallinule	0.95	
Pukeko	0.95	Eason et al., 2002
Blackbird	>3[b]	Godfrey, 1986
Hedge sparrow	>3[b]	Godfrey, 1985
California quail	3.3	
Mallard	4.6	
Black-billed gull	<5a	
House sparrow	>6[b]	
Silvereye	>6[b]	Eason et al. 2002
Ring-necked pheasant	10	Godfrey, 1986
Australasian harrier	10	
Paradise shelduck	>20[b]	Eason et al., 2002

[a] the lowest concentration tested
[b] the highest concentration tested

Because this assessment focused on consumption of pellets and mice over a long period of time, the preferred effects metric would be from a dietary exposure study. The dietary route of exposure is preferred over oral gavage exposures (i.e., acute oral tests) because gavage exposures

are generally relevant to situations where active ingredients are ingested rapidly and in large doses (e.g., consumption of pesticide granules) (ECOFRAM, 1999; EPA, 2004).

For this assessment, the lowest LD50 available, 0.26 mg a.i./kg bw (EPA, 1998a) for mallards, was used to be conservative because there was no accepted LD50 for gulls. This value was also used by FWS (2007) in the environmental assessment for Rat Island. Raw toxicity data were unavailable from the mallard study to generate a probit slope of dose-response for the model. Thus, the probit slope was calculated from a gull toxicity study, as described below.

The sensitivity of western gulls to brodifacoum exposure is most likely in the range demonstrated for other gull species. Based on reviews conducted by Godfrey (1985), Eason et al. (2002), Erickson and Urban (2004) and Bowie and Ross (2006), LD50s for gull species were <0.75 mg ai/kg bw for the southern black-backed gull (*Larus dominicanus*) and <5 mg ai/kg bw for the black-billed gull (*Larus bulleri*). For both species, however, the lowest dose tested resulted in 100% mortality. Thus, there were insufficient data for deriving dose-response curves. Although not included in the above reviews, dietary toxicity data of sufficient quality were available to derive a dose-response curve for the laughing gull (*Larus atricilla*). The toxicity data were from two studies conducted by Wildlife International (1979a,b). Birds were acclimated for two weeks at which point they were randomly assigned to either a control diet consisting of toxicant-free masticated rodent tissue or one of ten treatment diets (both studies combined) consisting of spiked masticated rodent tissue. Five birds were placed in each dietary treatment. Exposure continued for 5 days followed by an additional 5-week exposure period in which all birds were maintained on a diet of Southern States cat food.

For the statistical analysis, daily treatment dose was calculated by multiplying treatment concentration by the corresponding average measured food intake rate. The daily treatment doses were then normalized to average gull body weight (average of 5 gulls/treatment on days 0 and 6). Finally, the doses were summed across the 5 days of exposure. The latter step assumes that metabolism and elimination of brodifacoum during the 5-day exposure period would have been minimal (Fisher, 2009; see also Erickson and Urban, 2004). The statistical analysis was carried out in SAS using PROC PROBIT with dose log10 transformed. The fitted LD50 was 0.588 mg ai/kg bw and the probit slope was 2.32 (Figure 4-1).

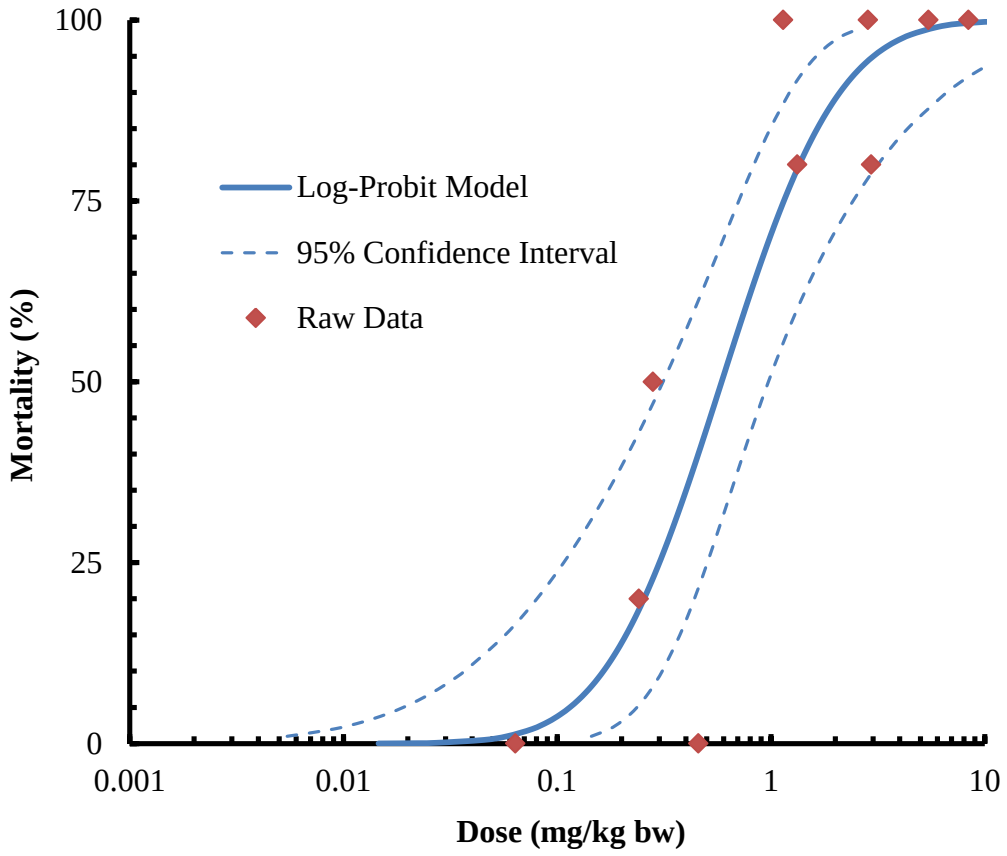

Figure 4-1. Dose-response relationship for effects of brodifacoum on laughing gulls.

4.2 EFFECTS METRICS FOR DIPHACINONE

Avian toxicity studies have been conducted for diphacinone, but none have involved gull species (EPA, 1998a; Erickson and Urban, 2004; Rattner et al., 2010, 2011, 2012). Additionally, acute oral gavage studies may underestimate toxicity for diphacinone because multiple feedings are typically required to evoke lethality (Vyas and Rattner, 2012). For this assessment, we used data from a screech owl dietary toxicity study (Rattner et al., 2012). Owls were exposed to diphacinone in the diet for seven days and observed for toxicity. At the highest concentration tested, 22.6 mg a.i./kg diet, 33% mortality was observed. This result served both as the LC33 and the lowest lethal dose (LLD). Using body weight and food consumption data, the authors calculated a cumulative LLD of 5.75 mg/kg, which is more than an order of magnitude less than the LLD (171 mg/kg) they observed in acute toxicity trials and which equates to a daily dose of 0.82 mg a.i./kg bw/day (Rattner et al., 2012). This latter value was used in the model. Because an LD50 was not available, the effects metric used is considered conservative. To generate a probit slope, we used the results for American kestrels from Rattner et al. (2010, 2011) as a surrogate

for the western gull. A log-probit regression analysis conducted by the study authors indicated an LD50 of 97 mg ai/kg bw with a probit slope of 6.69.

4.3 ORAL GAVAGE VERSUS DIETARY EXPOSURE STUDIES

Often oral gavage studies differ in estimates of toxicity compared to dietary studies. In dietary studies, metabolism and excretion over the course of the study can reduce accumulation of the pesticide thus reducing toxicity compared to oral gavage studies (EPA, 2004). In the case of brodifacoum, metabolism and excretion are unlikely to mediate toxicity when ingested over an extended period because the compound is highly persistent (Eason et al., 2002). The mean liver retention time for brodifacoum in birds is 217 days (Erickson and Urban, 2004). There are significant differences between toxicity results from oral gavage and dietary exposure studies for diphacinone (and other first generation anticoagulant rodenticides) given the mode of action and time course for toxicity (Vyas and Rattner, 2012). Acute oral toxicity studies can underestimate toxicity when multiple feedings are necessary to evoke lethality (Rattner et al., 2012).

5.0 RISK CHARACTERIZATION

Model runs were conducted to determine how different application options (e.g., different application dates, differing rates of hazing success, etc.) for brodifacoum and diphacinone affected predictions regarding mortality of western gulls. The following sections describe the results of an analysis conducted to determine how many simulations were required to produce consistent model predictions. Subsequent sections describe the results of the model analyses conducted for brodifacoum and diphacinone. An analysis conducted by Nur et al. (2012) for western gulls on SFI indicated that a one-time mortality event of up to 1700 individual gulls would not result in a detectably significant change in the population trend of the western gull on the Farallones over a 20-year period. We compare our model predictions to this benchmark in this chapter.

5.1 MODEL STABILITY

A model stability analysis was performed on the western gull risk model to determine the number of model simulations required to produce estimates of proportion mortality that are consistent from one model run to the next. The baseline scenario for this analysis assumed an initial application date of November 29 for brodifacoum, a hazing success rate of 90%[1], the time to the first significant rainfall event after the second and final application of 28 days, and 4.5 days of bait availability following a significant rainfall event. All other input parameters are those listed in Table 3-1. We ran the model for simulation sizes ranging from 100 to 100,000 simulations, and the model was run 10 times for each simulation size. As expected, variability in predictions regarding proportion mortality decreased as the number of simulations increases (Figures 5-1 and 5-2). The proportion of gulls at SFI experiencing mortality had a wide range of 0.0780 to 0.106 for 100 simulation model runs but a much narrower range of 0.0894 to 0.0902 for 100,000 simulation model runs. Further, the coefficients of variation for 100 and 100,000 simulation model runs were 10.3 and 0.287, respectively. Clearly, the more simulations, the lower the coefficient of variation and the increased likelihood that model runs will produce consistent predictions. For this assessment, 30,000 simulations were conducted for each model run because the coefficient of variation was quite low (0.603) with this number of simulations. In addition, little was gained in terms of model stability by increasing the number of simulations to 100,000 (Figures 5-1 and 5-2).

[1] The inputs chosen for the model stability analysis are unimportant in determining how many simulations are required to ensure a stable output (i.e., a consistent answer). Thus, readers should not interpret the inputs chosen for this analysis as being in any way relevant to the actual analyses of risk to western gulls. For example, in the actual analyses of risk to western gulls, we varied hazing success from 75 to 98% and application dates from November 1 to December 20.

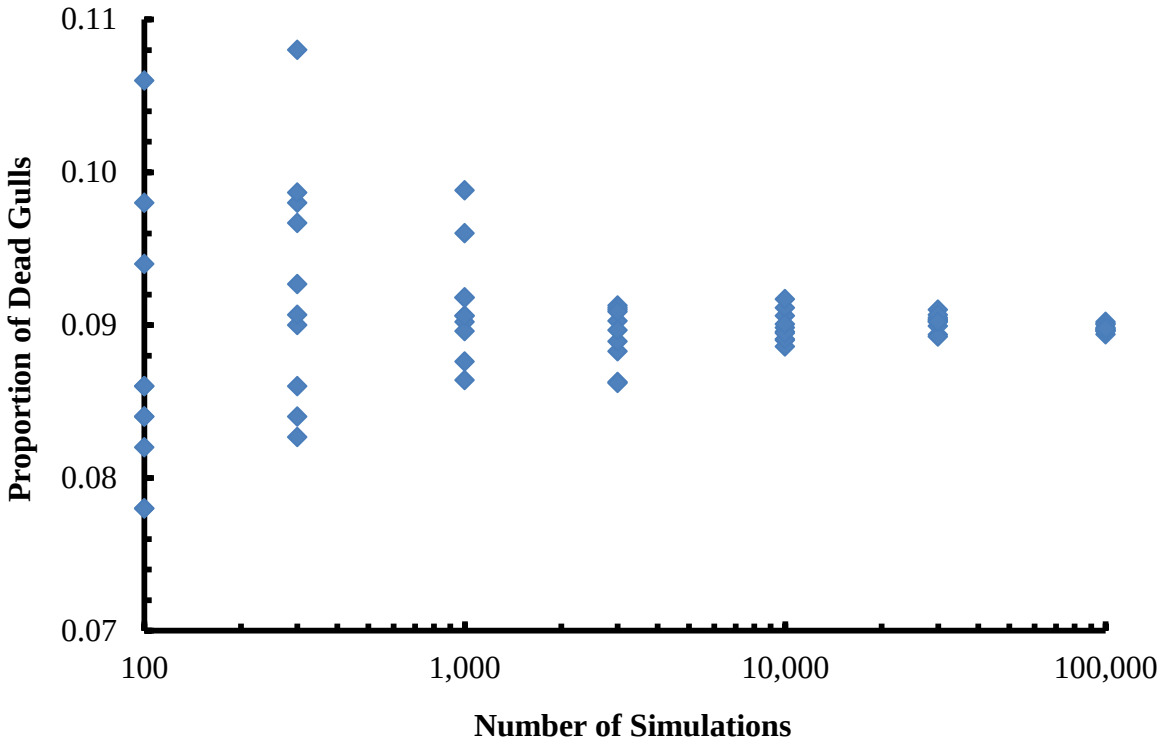

Figure 5-1. Results of the model stability analysis for proportion of dead western gulls exposed to brodifacoum in relation to the number of simulations. The analyses assumed a start date of November 29, a hazing success rate of 90%, and a time to first significant rainfall event after the final application of 28 days. All other assumptions are listed in Table 3-1.

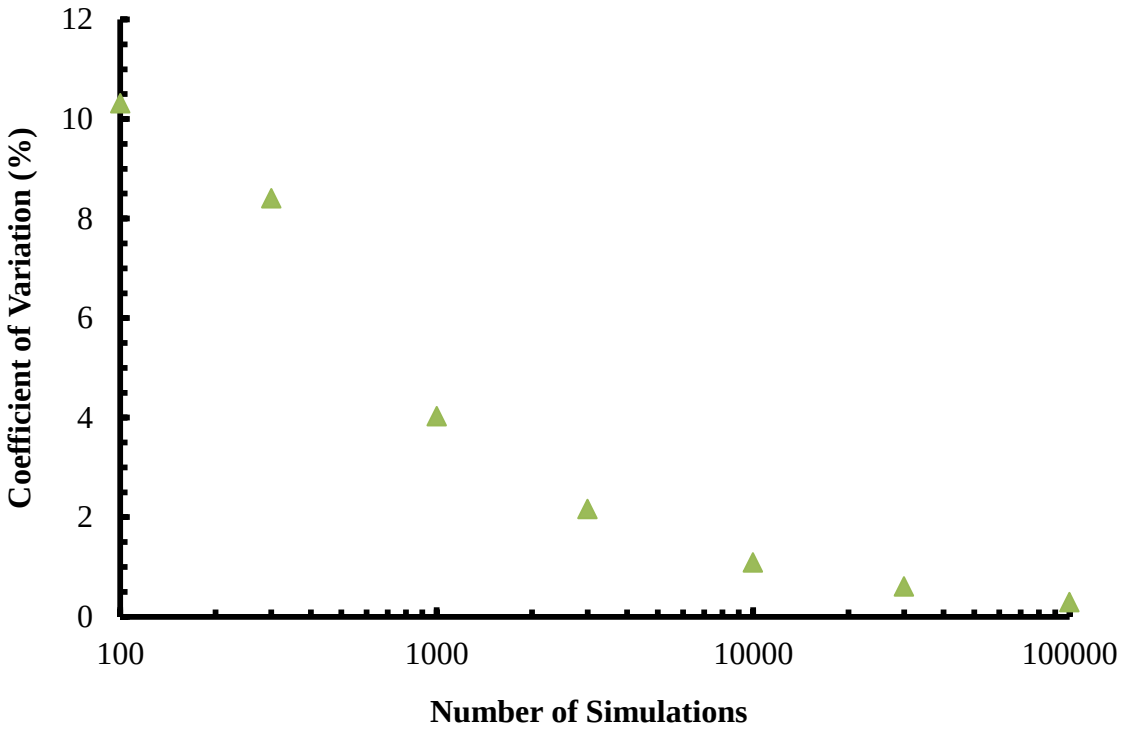

Figure 5-2. Results of the model stability analysis for the coefficient of variation of proportion of dead gulls exposed to brodifacoum in relation to number of simulations. The analyses assumed a start date of November 29, a hazing success rate of 90%, and a time to first significant rainfall event after the final application of 28 days. All other assumptions are listed in Table 3-1.

5.2 MODEL RESULTS FOR BRODIFACOUM

The results of all model runs conducted for brodifacoum can be found in Appendix A. The following sections summarize the results for each of the major factors considered potentially important in designing an application and risk management strategy for brodifacoum. Results are presented as the proportion and number of western gulls present at some point on SFI during the period November 1 to end of March that experience mortality based on various modifications of the input parameters, assuming a population of 11,000 western gulls. The text and figures below provide examples from the various possible scenarios.

5.2.1 Initial Application Date

Model runs were performed to determine how initial application date of brodifacoum affected the proportion of (Figure 5-3, Appendix A) and number of western gulls dying from rodenticide exposure (Figure 5-4, Appendix A) on SFI. The results shown in Figures 5-3 and 5-4 involved a scenario where hazing was assumed to be 90% effective, and the first significant rainfall occurred 30 days after the second application. All other input values are listed in Table 3-1. The

results from other scenarios are shown in Appendix A. As shown in Figures 5-3 and 5-4, western gull mortality increases with later initial application dates, coinciding with the increased numbers of gulls being present on SFI. Predicted mortality did not change substantively with initial application date after approximately November 22nd. There is little difference in gull mortality with initial application date in models from drought years (Appendix A).

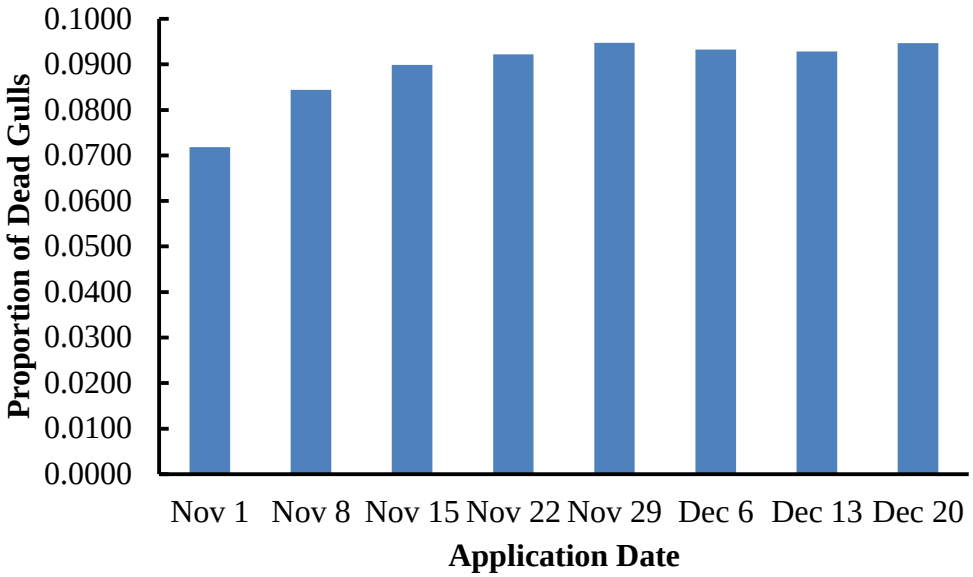

Figure 5-3. Model results for proportion of 11,000 western gulls dying as a result of varying initial application date for brodifacoum, assuming 90% hazing effectiveness and 30 days until the first significant rainfall. See Table 3-1 for other input values and Appendix A for other model scenarios.

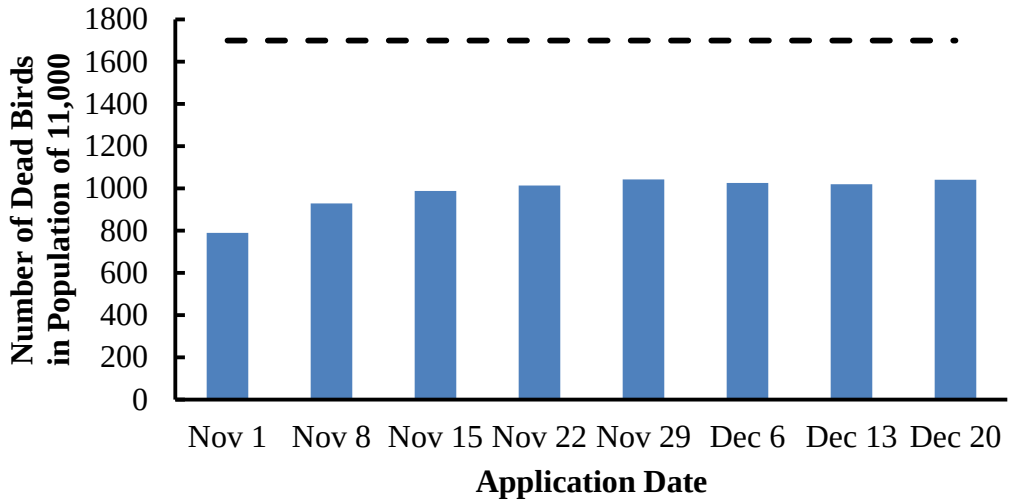

Figure 5-4. Model results for number of gulls dying as a result of varying initial application date for brodifacoum, assuming a population of 11,000 gulls, 90% hazing effectiveness and 30 days until the first significant rainfall. The dashed line represents 1700 dead gulls, the number considered the maximum possible without affecting long-term population viability. See Table 3-1 for other input values and Appendix A for other model scenarios.

5.2.2 Proportion of Gulls Removed From SFI by Hazing

The utility of hazing in reducing gull mortality was investigated by varying hazing success from 75% to 98%. For the results shown in Figures 5-5 and 5-6, the date of initial application was November 29th, and there were 30 days until the first significant rainfall following the second application (see Table 3-1 for other inputs). The results of other scenarios are shown in Appendix A. As expected, there was a strong negative relationship between gull mortality and hazing success (Figures 5-5 and 5-6) and the threshold of 1700 dead gulls was surpassed with 75% hazing success (Figure 5-6). The results in Appendix A indicate that 90% hazing success is required to ensure that the threshold of 1700 gulls is not surpassed for all possible initial application dates and to cover the range of possible dates over which the first significant rainfall event occurs following the second application of brodifacoum.

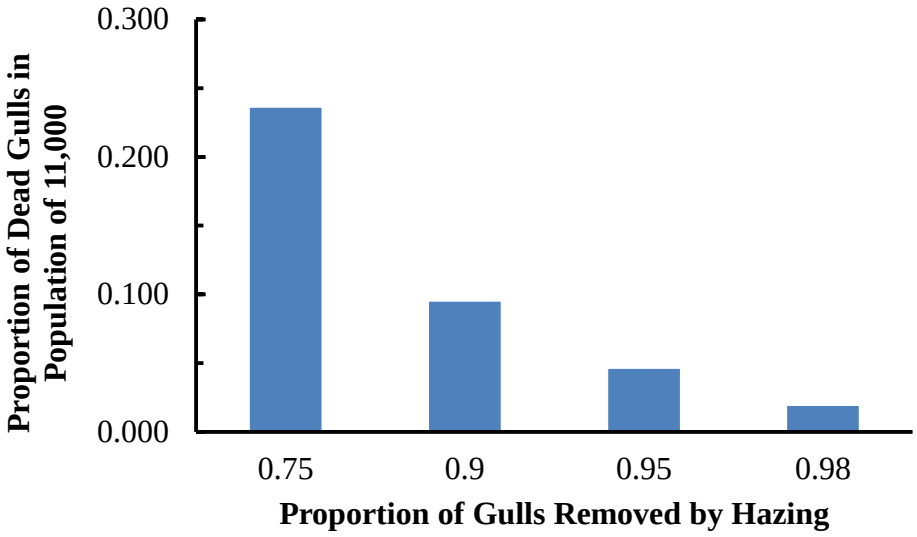

Figure 5-5. Model results for proportion of 11,000 gulls dying as a function of hazing success, assuming November 29th date of first application of brodifacoum and 30 days until the first significant rainfall. See Table 3-1 for other input values and Appendix A for other model scenarios.

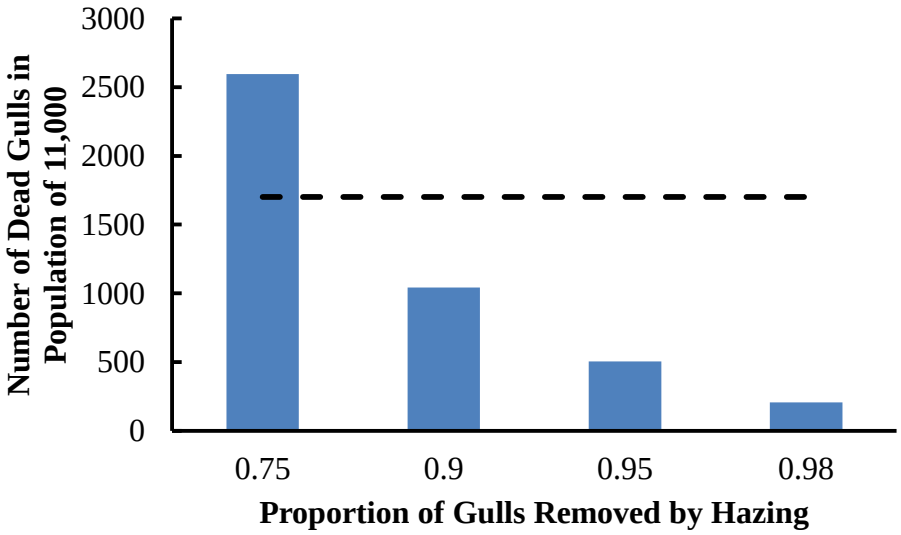

Figure 5-6. Model results for number of gulls dying as a function of hazing success, assuming November 29th date of first application of brodifacoum and 30 days until the first significant rainfall. The dashed line represents 1700 dead gulls. See Table 3-1 for other input values and Appendix A for other model scenarios.

5.2.3 Time to Significant Rainfall Event

A significant rainfall event is one in which sufficient rain falls to degrade remaining bait pellets. Dates of historic rainfall events were compiled and analyzed to determine a best, worst, and most likely scenario. The model was then run to determine the proportion (Figure 5-7) and number (Figure 5-8) of dead birds following each length of time until the rainfall event. The scenario shown in Figures 5-7 and 5-8 assumed an initial application date of November 29th and that hazing success was 90% (see Table 3-1 for other inputs). The results indicate that the proportion and number of dead birds increased with increasing time until the rainfall event. However, the quantity of dead birds was below the threshold of 1700 dead birds for all scenarios with at least 90% hazing success (Appendix A).

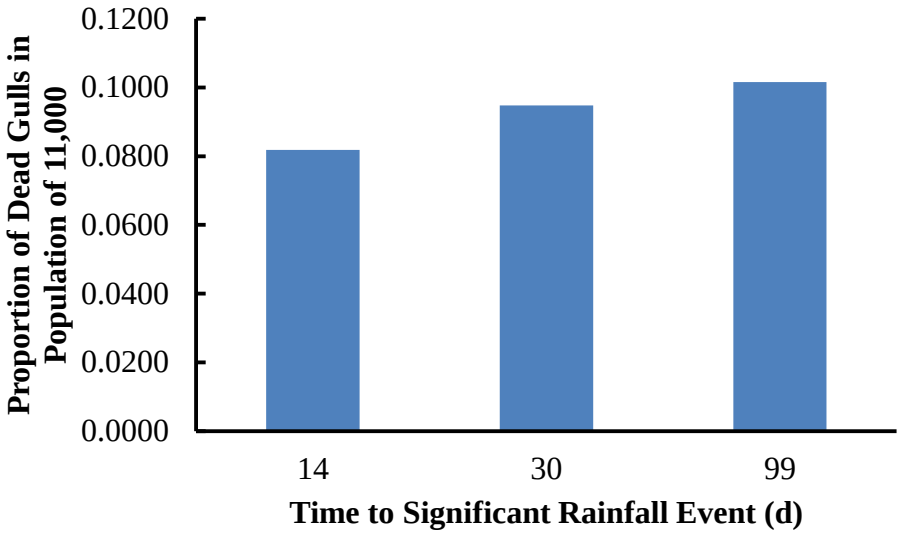

Figure 5-7. Model results for proportion of 11,000 gulls dying as a function of time to significant rainfall after the second application of brodifacoum, assuming November 29th date of first application and 90% hazing effectiveness. See Table 3-1 for other input values and Appendix A for other model scenarios.

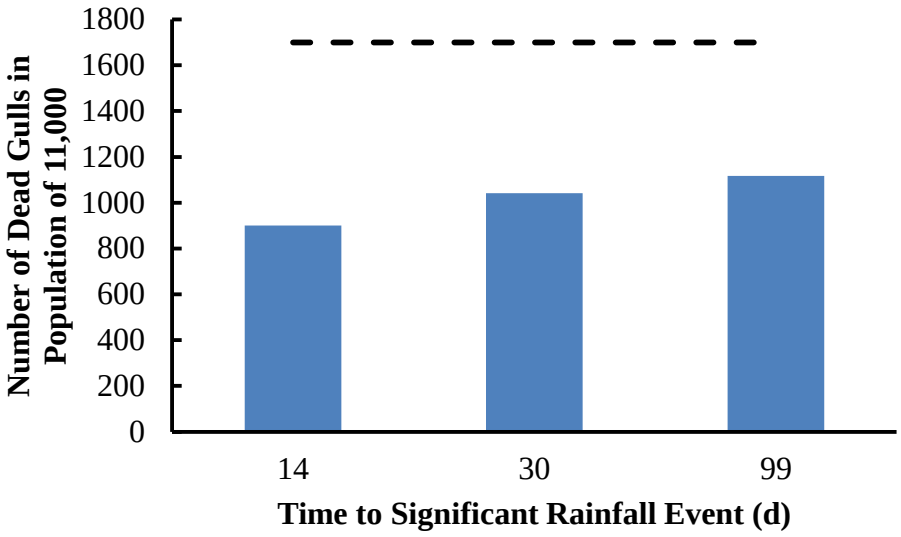

Figure 5-8. Model results for number of gulls dying as a function of time to significant rainfall after the second application of brodifacoum, assuming November 29th date of first application and 90% hazing effectiveness. The dashed line represents 1700 dead gulls. See Table 3-1 for other input values and Appendix A for other model scenarios.

5.2.4 Number of Applications

Based on the greater gull mortalities modeled with 2 applications compared to a single application, it is clear that the greatest risk to gulls is from ingestion of pellets remaining after the second application (Figures 5-9 and 5-10). The results shown in Figure 5-9 and 5-10 assumed an initial application date of November 29th, 90% hazing effectiveness, and 30 days until the first significant rainfall for the scenario involving two applications (see Table 3-1 for other inputs). Approximately 5 times more gulls died when two applications took place. However, applying only one application would not be best practice and that would likely compromise the effectiveness of the mouse eradication, which requires 100% lethal exposure to all mice.

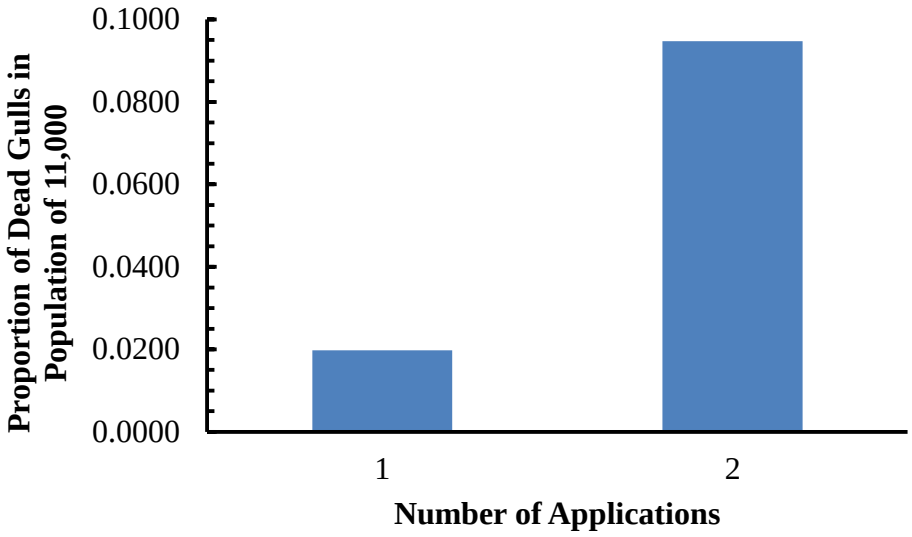

Figure 5-9. Model results for proportion of 11,000 gulls dying as a function of number of applications of brodifacoum, assuming an initial application date of November 29th, 90% hazing effectiveness, and 30 days until the first significant rainfall. See Table 3-1 for other input values and Appendix A for other model scenarios.

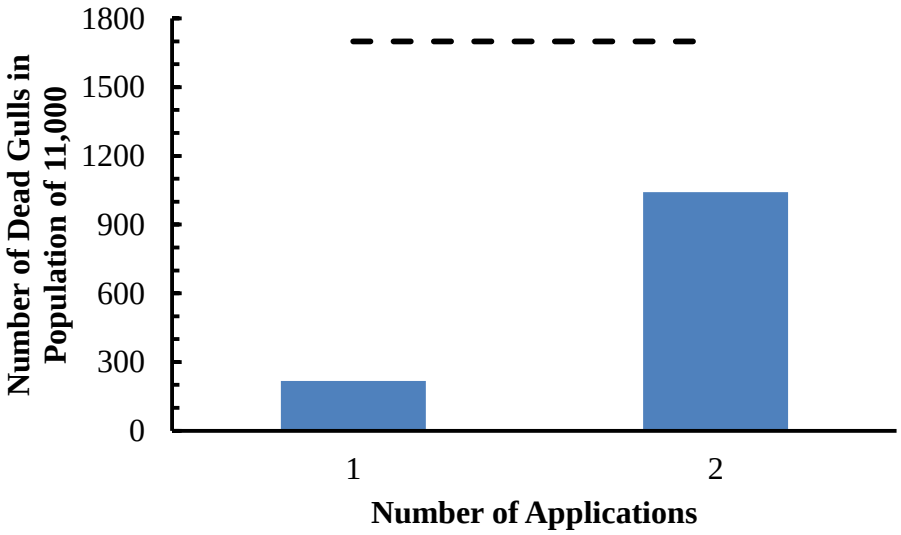

Figure 5-10. Model results for number of gulls dying as a function of number of applications of brodifacoum, assuming an initial application date of November 29th, 90% hazing effectiveness, and 30 days until the first significant rainfall. The dashed line represents 1700 dead gulls. See Table 3-1 for other input values and Appendix A for other model scenarios.

5.2.5 Removal of Dead Mice

One possible management option to reduce mortality of western gulls is to remove dead mouse carcasses as they are discovered. Assuming an initial application date of November 29th, 90% hazing effectiveness, and 30 days until the first rainfall (see Table 3-1 for other inputs), the results indicate no differences in the proportion and number of dead gulls as a result of not removing or removing dead mice (Figures 5-11 and 5-12). For brodifacoum, it appears that removal of dead mice would accomplish little in terms of reducing mortality of western gulls given the greater risk from ingestion of remaining pellets.

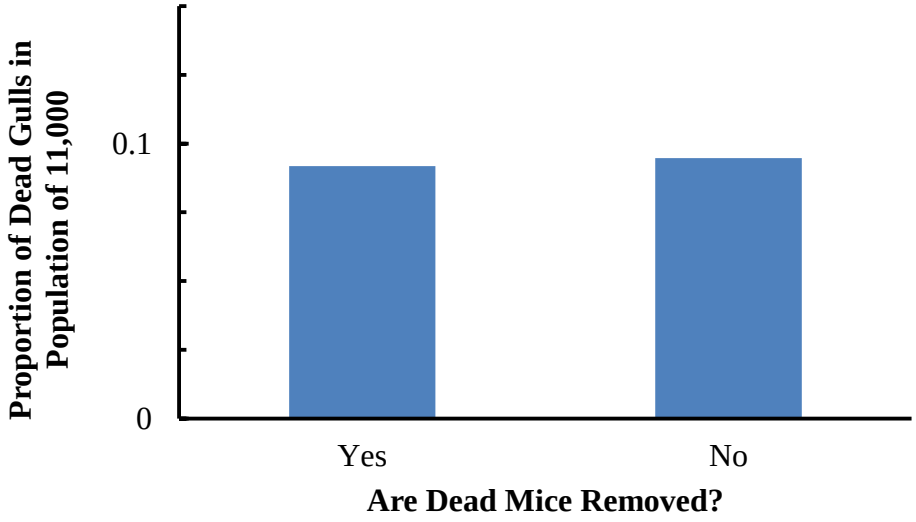

Figure 5-11. Model results for proportion of 11,000 gulls dying as a function of whether or not dead mice are removed, assuming an initial application date for brodifacoum of November 29th, 90% hazing effectiveness, and 30 days until the first significant rainfall. See Table 3-1 for other input values and Appendix A for other model scenarios.

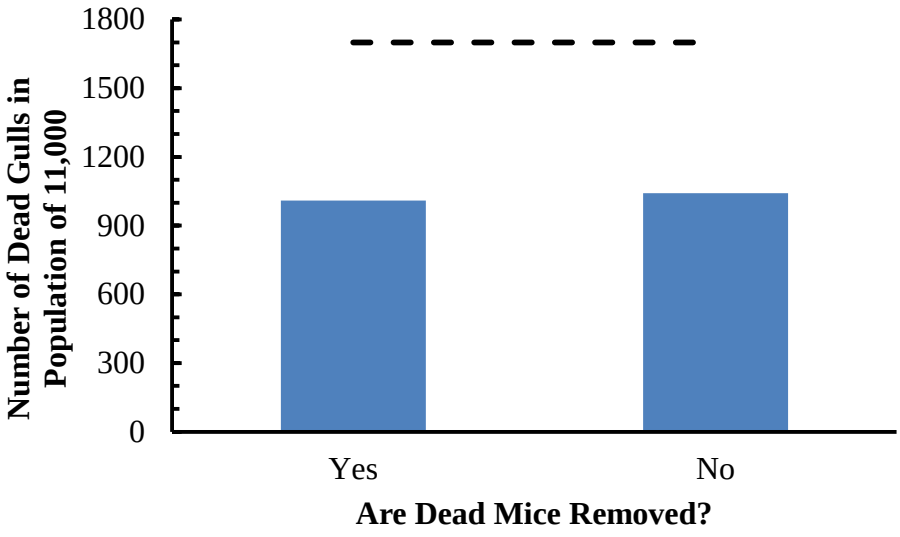

Figure 5-12. Model results for number of gulls dying as a function of whether or not mice are removed, assuming an initial application date for brodifacoum of November 29th, 90% hazing effectiveness, and 30 days until the first significant rainfall. The dashed line represents 1700 dead gulls. See Table 3-1 for other input values and Appendix A for other model scenarios.

5.3 MODEL RESULTS FOR DIPHACINONE

The results of all model runs conducted for diphacinone can be found in Appendix B. The following sections summarize the results for each of the major factors considered potentially important in designing an application and risk management strategy for diphacinone. Results are presented as the proportion and number of western gulls present at some point on SFI during the period November 1 to end of March that experience mortality based on various modifications of the input parameters, assuming a population of 11,000 western gulls. The text and figures below provide examples from the various possible scenarios.

5.3.1 Initial Application Date

Possible application dates for diphacinone were modeled to determine if the initial application date impacted the proportion (Figure 5-13) and number (Figure 5-14) of gulls dying. The results presented in Figures 5-13 and 5-14 assumed a hazing effectiveness of 90% and that the first rainfall event occurred 96 days after the second application (see Table 3-1 for other inputs). As with the brodifacoum model under drought conditions, there is little difference in gull mortality with initial application date (Appendix B).

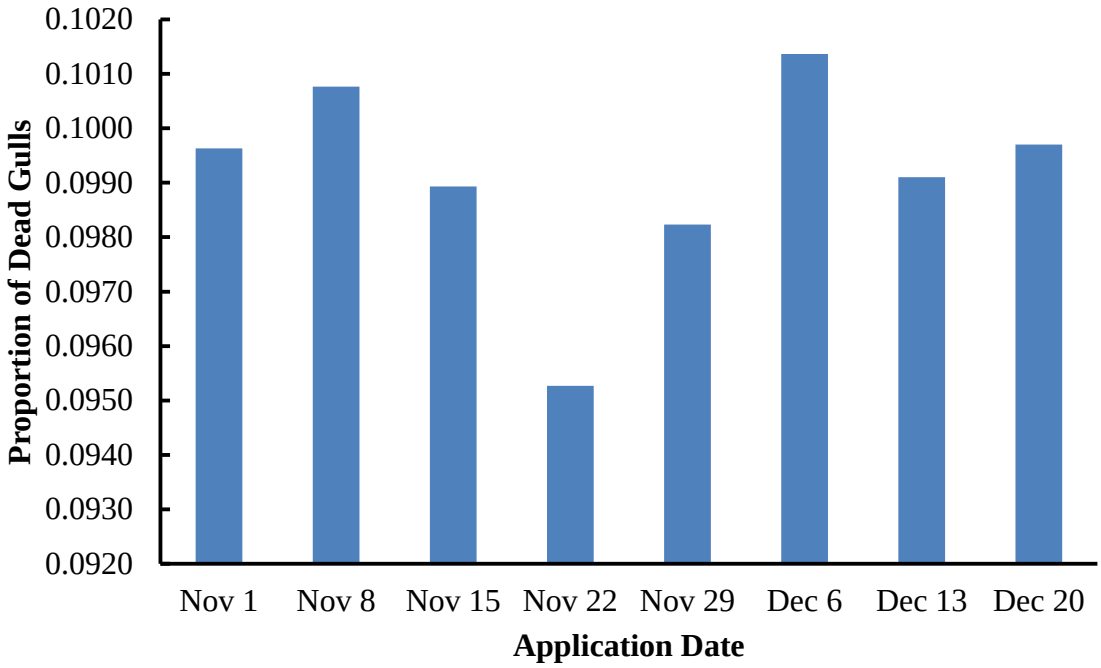

Figure 5-13. Model results for proportion of 11,000 gulls dying as a result of varying initial application date for diphacinone, assuming an initial application date of November 29th, 90% hazing effectiveness, and 96 days until the first significant rainfall. See Table 3-1 for other input values and Appendix B for other model scenarios.

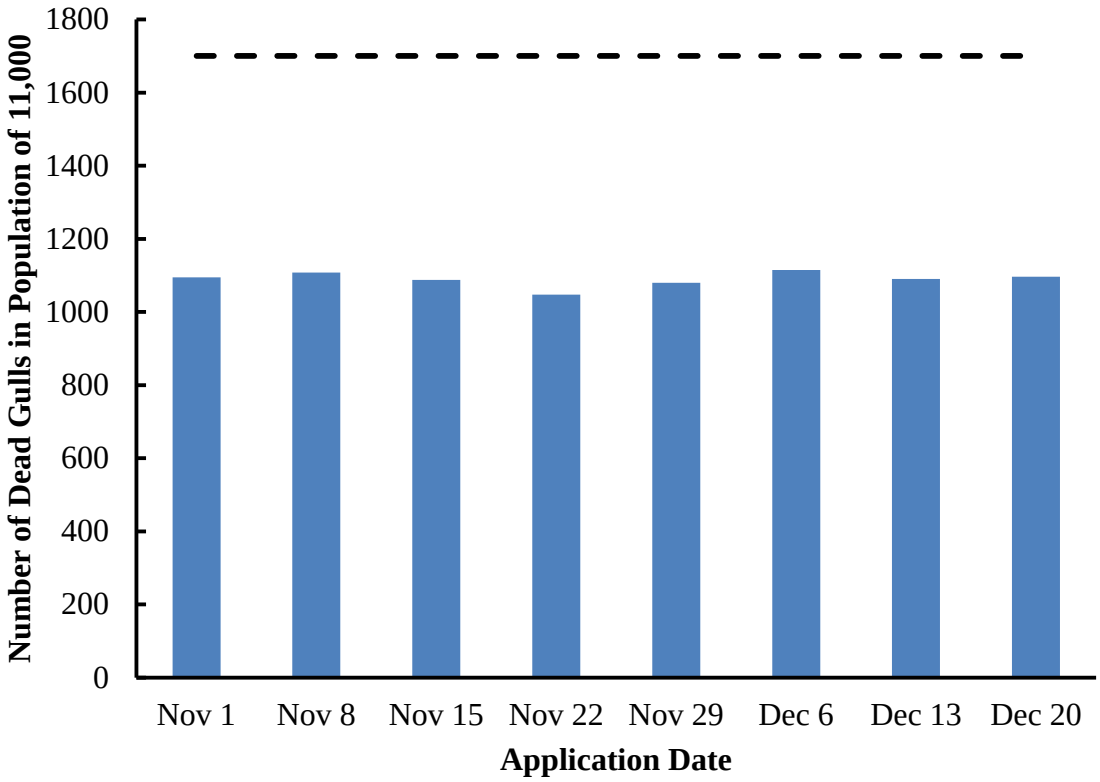

Figure 5-14. Model results for number of dead gulls as a result of varying initial application date for diphacinone, assuming an initial application date of November 29th, 90% hazing effectiveness, and 96 days until the first significant rainfall. The dashed line represents 1700 dead gulls. See Table 3-1 for other input values and Appendix B for other model scenarios.

5.3.2 Proportion of Gulls Removed From SFI by Hazing

The utility of hazing in reducing gull mortality was investigated by varying hazing success from 75 to 98%. The results shown in Figures 5-15 and 5-16 assumed an initial application date of November 29th, and that the first significant rainfall event occurred 96 days after the second application of diphacinone (see Table 3-1 for other inputs and Appendix B for results of other model scenarios). As expected, the proportion and number of gulls dying decreased as hazing effectiveness increased. At 75% hazing effectiveness, the number of dead gulls was above the threshold of 1700.

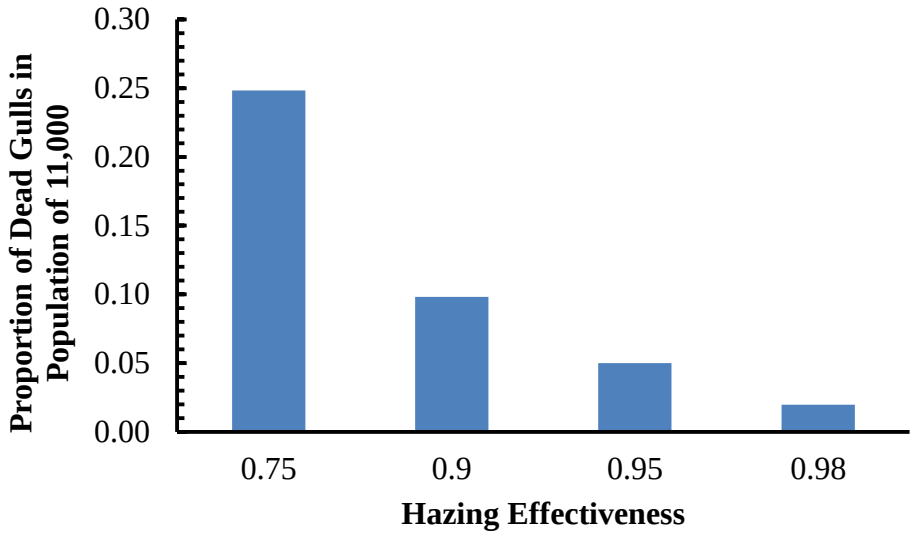

Figure 5-15. Model results for proportion of 11,000 gulls dying as a function of hazing success, assuming an initial application date for diphacinone of November 29th, and 96 days until the first significant rainfall. See Table 3-1 for other input values and Appendix B for other model scenarios.

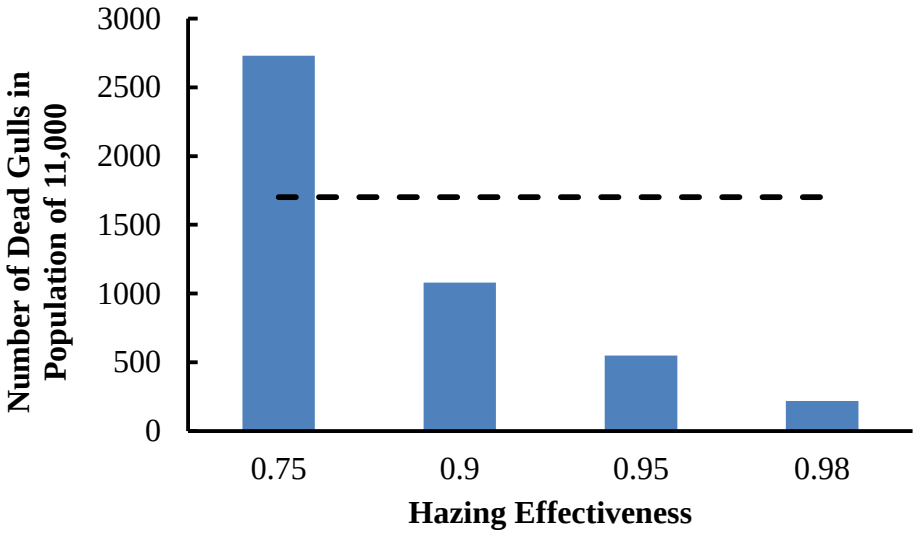

Figure 5-16. Model results for number of gulls dying as a function of hazing success, assuming an initial application date of November 29th and 96 days until the first significant rainfall. The dashed line represents 1700 dead gulls. See Table 3-1 for other input values and Appendix B for other model scenarios.

5.3.3 Time to Significant Rainfall Event

The impact of time to a significant rainfall event after the second application was not evaluated for diphacinone because only one value was available, i.e., 96 days between application and degradation.

5.3.4 Number of Applications

The effect on number of applications was modeled for 1, 2 and 3 applications of diphacinone. The results shown in Figures 5-19 and 5-20 assumed an initial application date of November 29th, 90% hazing effectiveness, and 96 days until the first significant rainfall event after the second application (see Table 3-1 for other inputs). The results indicate that the greatest risk to gull mortality occurs after the second application.

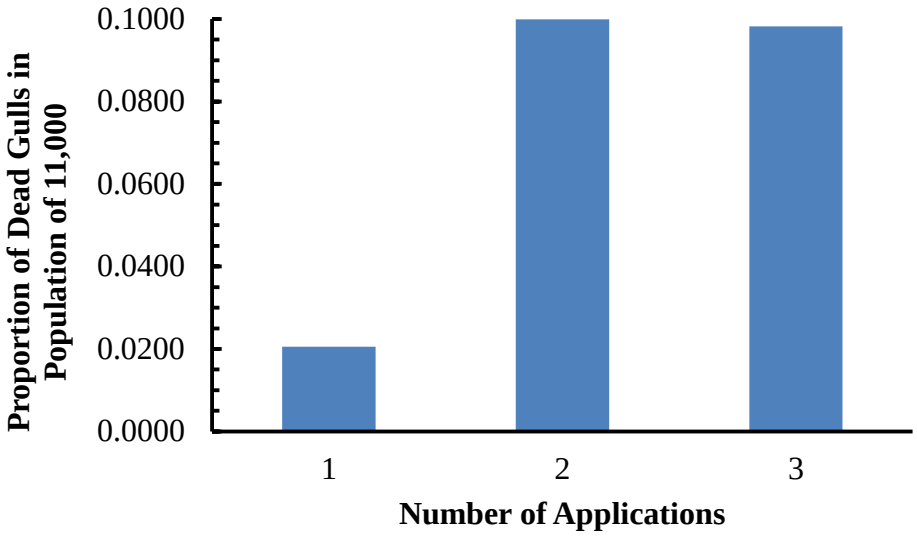

Figure 5-19. Model results for proportion of 11,000 gulls dying as a function of number of applications of diphacinone, assuming an initial application date of November 29th, 96 days to first significant rainfall, and 90% hazing effectiveness. See Table 3-1 for other input values and Appendix B for other model scenarios.

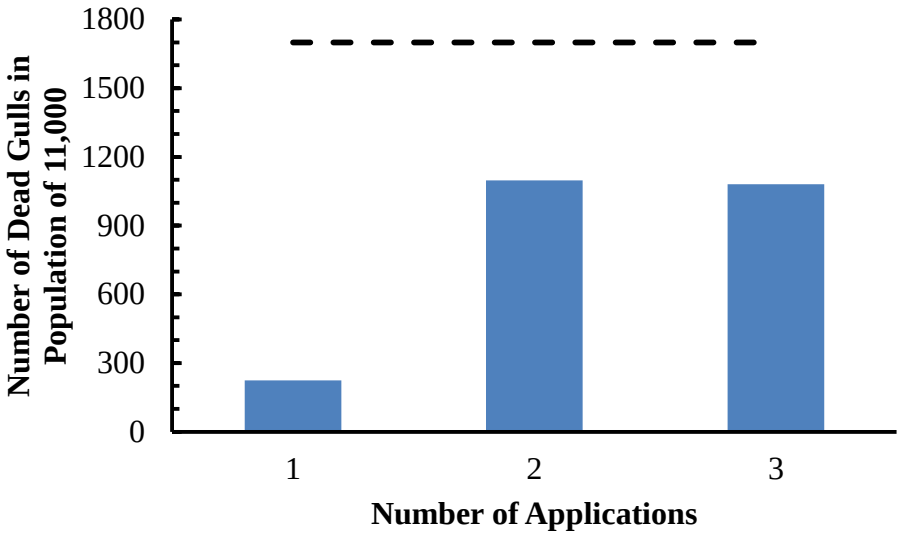

Figure 5-20. Model results for number of gulls dying as a function of number of applications of diphacinone, assuming an initial application date of November 29th, 96 days to first significant rainfall, and 90% hazing effectiveness. The dash line represents 1700 dead gulls. See Table 3-1 for other input values and Appendix B for other model scenarios.

5.3.5 Removal of Dead Mice

Removal of dead mice was modeled to determine if this mitigation practice would reduce gull mortality. The results shown in Figures 5-21 and 5-22 assumed an initial application date of November 29th, 90% hazing effectiveness, and 96 days until the first significant rainfall event after the second application (see Table 3-1 for other inputs). As with brodifacoum, removing dead mice did not significantly improve the survival of western gulls exposed to diphacinone given the greater risk from ingestion of pellets.

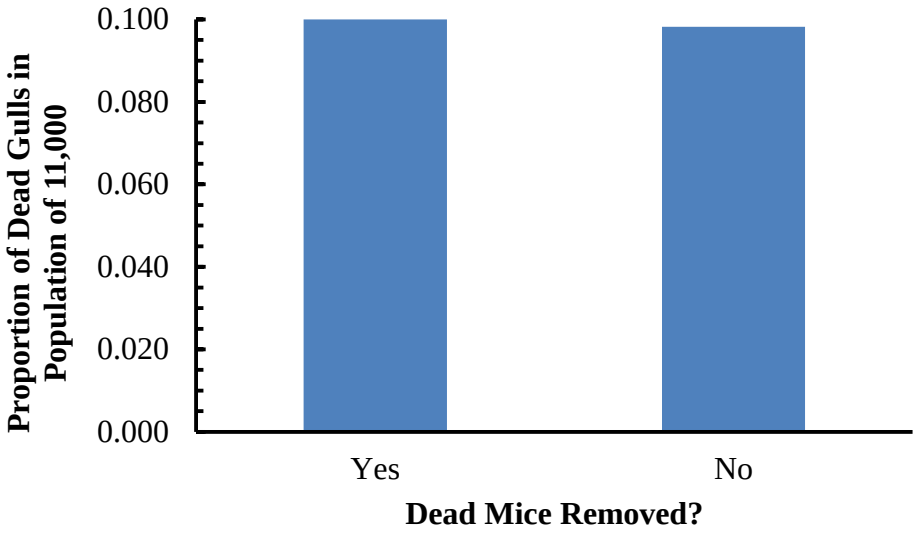

Figure 5-21. Model results for proportion of 11,000 gulls dying as a function of whether or not mice are removed, assuming an initial application date for diphacinone of November 29th, 96 days to first significant rainfall, and 90% hazing effectiveness. See Table 3-1 for other input values and Appendix B for other model scenarios.

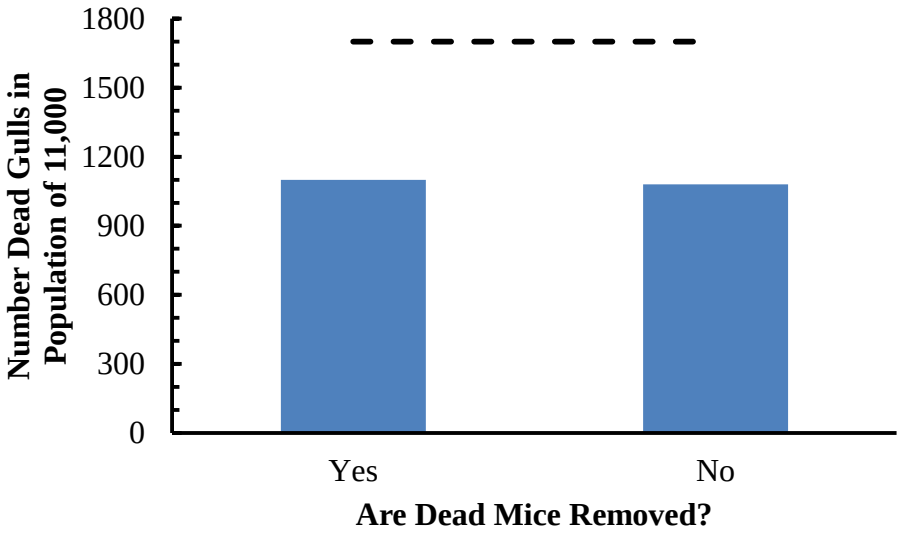

Figure 5-22. Model results for number of gulls dying as a function of whether or not mice are removed. The dashed line represents 1700 dead gulls, assuming an initial application date for diphacinone of November 29th, 96 days to first significant rainfall, and 90% hazing effectiveness. See Table 3-1 for other input values and Appendix B for other model scenarios.

5.4 SENSITIVITY ANALYSIS

The purpose of the sensitivity analysis is to identify how variation in the output of a model (e.g., number of dead birds) is influenced by uncertainty in the input variables. If the output variability precludes effective decision making, sensitivity analysis may be used to identify the input variables that contribute the most to the observed output variability. Subsequently, research efforts may be initiated to reduce uncertainty in those input variables.

Uncertainty and sensitivity analyses both focus on the output of a model and are therefore closely related. However, the purposes of the two types of analyses are different. An uncertainty analysis assesses the uncertainty in model outputs that derives from uncertainty in the inputs. A sensitivity analysis assesses the contributions of the inputs to the total uncertainty in the output.

Sensitivity analysis methods may be classified into three groups: screening methods, methods for local sensitivity analysis, and methods for global sensitivity analysis. Screening methods are generally used to separate influential input variables from non-influential ones, rather than quantify the impact that an input variable has on the output of the model. Screening methods are useful for models with large numbers of input variables. They are able to identify important input variables with little computational effort, but at a cost of losing quantitative information on the importance of the input variables. In contrast, local and global sensitivity measures provide quantitative estimates of the importance of each input variable. The difference between them is that the former focuses on estimating the impact of small changes in input variable values on model output, while the latter addresses the contribution to model output variance over the entire range of each input variable distribution.

Most screening methods revolve around the idea of "what if" analyses. That is, how would the outputs change if the value of a selected input variable was changed? With large models, this exercise needs to be systematic to be useful. Factorial designs, for example, are used to measure the influence of input variables on the output by taking into account both additive effects and interactions. The design involves selecting combinations of input variable values that provide the most information on the relationships between input and output variables. However, with a factorial design and a large model, the number of model runs (n^k, where k is the number of input variables, and n is the number of levels for each variable) quickly becomes unmanageable. Given the complexity of the western gull risk model, this approach was infeasible for this assessment.

One way to overcome the difficulties of a factorial design method is to set all input variable values to achieve the most likely response and only increase or decrease one input variable at a time (Cotter, 1979). The sensitivity analyses for the western gull risk models for brodifacoum and diphacinone relied on "what if" analyses using a "one-at-a-time" design. The baseline scenarios for brodifacoum and diphacinone assumed the input values in Table 3-1 except for the variable being investigated. Each variable being investigated was altered one at a time to explore the influence on the model outputs. The inputs values selected for the sensitivity analyses are

listed in Table 5-1. Some of these values could be adjusted in future model simulations as, for example, new data become available.

Table 5-1. Values of input parameters varied in one at-a-time sensitivity analyses for western gull risk models for brodifacoum and diphacinone.

Variable	Values	Notes
First application date	Nov 1, 8, 15, 22, 29 and Dec 6, 13 and 20	This is the range of possible application dates being considered for SFI.
Applications interval - brodifacoum	5, 21 days	Label does not permit intervals of <5 days. An interval of 21 days or more will increase the likelihood that all individuals are exposed to the technique (Griffiths and Towns, 2008)
Applications interval - diphacinone	3, 10 days	No need for interval of less than 3 days to ensure availability of pellets. Mice could recover if pellets not available for a period of time which suggests upper bound of 10 days.
Number of applications - brodifacoum	1, 2	2 applications is maximum indicated in Draft EIS (FWS, 2012). 1 application is likely to be ineffective at eradicating mice.
Number of applications - diphacinone	1, 2, 3	3 applications is maximum indicated in Draft EIS (FWS, 2013). 1 or 2 applications are likely to be ineffective at eradicating mice.
Hazing effectiveness	0.75, 0.98	Range suggested by Warzybok et al. 2013.
Pellet half-life (1st application)	0.5, 2 days	2010 SFI field trial (Pott & Grout 2012) and available literature indicate this approximate range.
Time to significant rainfall event after 2nd application - brodifacoum	14, 99 days	Best and worst case scenarios are14 and 99 days, respectively.
Mean concentration in mice - brodifacoum	2.71, 4.9 mg/kg bw	Range cited in Howald et al. (1999, 2001). Standard deviation adjusted to ensure same coefficient of variation.
Mean concentration in mice - diphacinone	30, 51.5 mg/kg bw	Upper value is upper bound calculated from Pitt et al. (2011). Lower value is somewhat arbitrary but approximately the lower bound value if there was some initial rapid elimination of diphacinone from the exposed mice in Pitt et al. (2011) study.
Daily probability of consuming mice	0.01, 0.15	Lower value reflects fact that mice are not normally part of the western gull diet. Upper value is arbitrary but kept generally low because gulls normally feed on other food items.
Daily probability of consuming pellets	0.22, 0.25	Highest average rate suggested by data collected during 2010 SFI field trial. Initial daily rates are much lower, ranging from 0 to 29% during first five days.
Conditional probability for consuming pellets	0.5, 0.9	Observational data from 2010 SFI field trial suggest that once a gull learns that pellets are a food source, they will continue to consume them as long as they are available. No data are available to quantify this variable and thus a wide range was selected. The same rationale was used for consumption of mice.
Conditional probability for consuming mice	0.5, 0.9	
Proportion of intoxicated mice below ground	0.87, 0.935, 1	Data from literature suggests that at least 87% of brodifacoum-intoxicated mice will go below ground. No comparable information is available for diphacinone.
LD50 - brodifacoum	0.26 - 0.588 mg/kg bw	Toxicity studies available for gull species indicate a range of 0.588 to <5 mg/kg bw (Wildlife International, 1979a,b; Godfrey, 1985, 1986), but lowest LD50 for mallards, 0.26 mg/kg bw used as minimum value.
LD50 - diphacinone	0.82 - 97 mg/kg bw	No gull toxicity studies are available. Used range observed for screech owl (0.82 mg/kg bw; Rattner et al., 2012) and American kestrel (97 mg/kg bw; Rattner et al., 2010).

5.4.1 Brodifacoum

Figures 5-23 to 5-25 show the results of the sensitivity analyses for brodifacoum for maximum gull tissue concentration, proportion mortality of gulls, and number of dead gulls. The results of the sensitivity analysis for maximum gull tissue concentration indicate that the three most important variables influencing exposure of western gulls to brodifacoum are the number of applications, hazing effectiveness and time to significant rainfall event following the second application (Figure 5-23). Hazing effectiveness is the most important variable, as it determines how many birds are foraging on the island during bait application and could, therefore, potentially consume the bait. Hazing has been shown to be highly effective (~90-98%) at airports and landfills (Curtis et al., 1995; Slate et al., 2000; Chipman et al., 2004) and a hazing trial conducted on SFI in December, 2013 achieved an average hazing efficiency of 98% providing confidence that hazing efficiencies of 90% or higher could be achieved for an extended period of time (Warzybok et al., 2013). Time to the first significant rainfall event following the second application is also significant because rain reduces availability of the pellets from gull exposure in the model, particularly after the second application when few, if any, mice are available to remove pellets. As a result, if there is an extended period of time to the first rainfall event after the second application, gulls will have much higher exposure risk due to the long-term availability of pellets. Although time to first significant rainfall event is a critical input variable, there is no need to conduct additional research on this variable. Thirty-eight years of data on daily rainfall at SFI are currently available (1972-2010), which is sufficient for determining best case, most likely case and worst case values for this variable.

The number of applications is a significant input variable because there will likely be very few mice available following the second application to consume the pellets. This increases the risk that the remaining pellets will be consumed by gulls. It is important that measures be taken to reduce the availability of pellets to gulls. This could be done by hazing, as the sensitivity analysis shows that effective hazing greatly reduces the dose ingested by the gulls. Overall, the most effective way to reduce exposure to gulls would be to enhance the hazing effort.

Varying the daily probability of gulls ingesting pellets from 0.22 to 0.25 had only a modest influence on gull exposure. Although data from the 2010 SFI trial were used to define this narrow range, the dataset was clearly limited and thus there is uncertainty regarding this input parameter. The 0.22-0.25 range was at the maximum end of the range actually observed at SFI using two different methods (proportion fecal pellets with dye and observations of foraging gulls). The conditional probability for ingesting pellets is also highly uncertain. However, varying this parameter value from 0.5 to 0.9 had little impact on predicted gull exposure. This result suggests that further research is not required for the conditional probability for ingesting pellets.

Variables related to the secondary route of exposure (e.g., concentration in mice, probability of consuming mice, conditional probability for consuming mice, proportion of intoxicated mice below ground) had little influence on predicted exposure to western gulls. As shown in Figures 5-11 and 5-12, total removal of dead or intoxicated mice would do little to reduce gull mortality. Clearly, exposure to pellets is a far more important contributor to gull exposure than is exposure to mice. Thus, no research is recommended to reduce uncertainty in the parameters related to the secondary route of exposure.

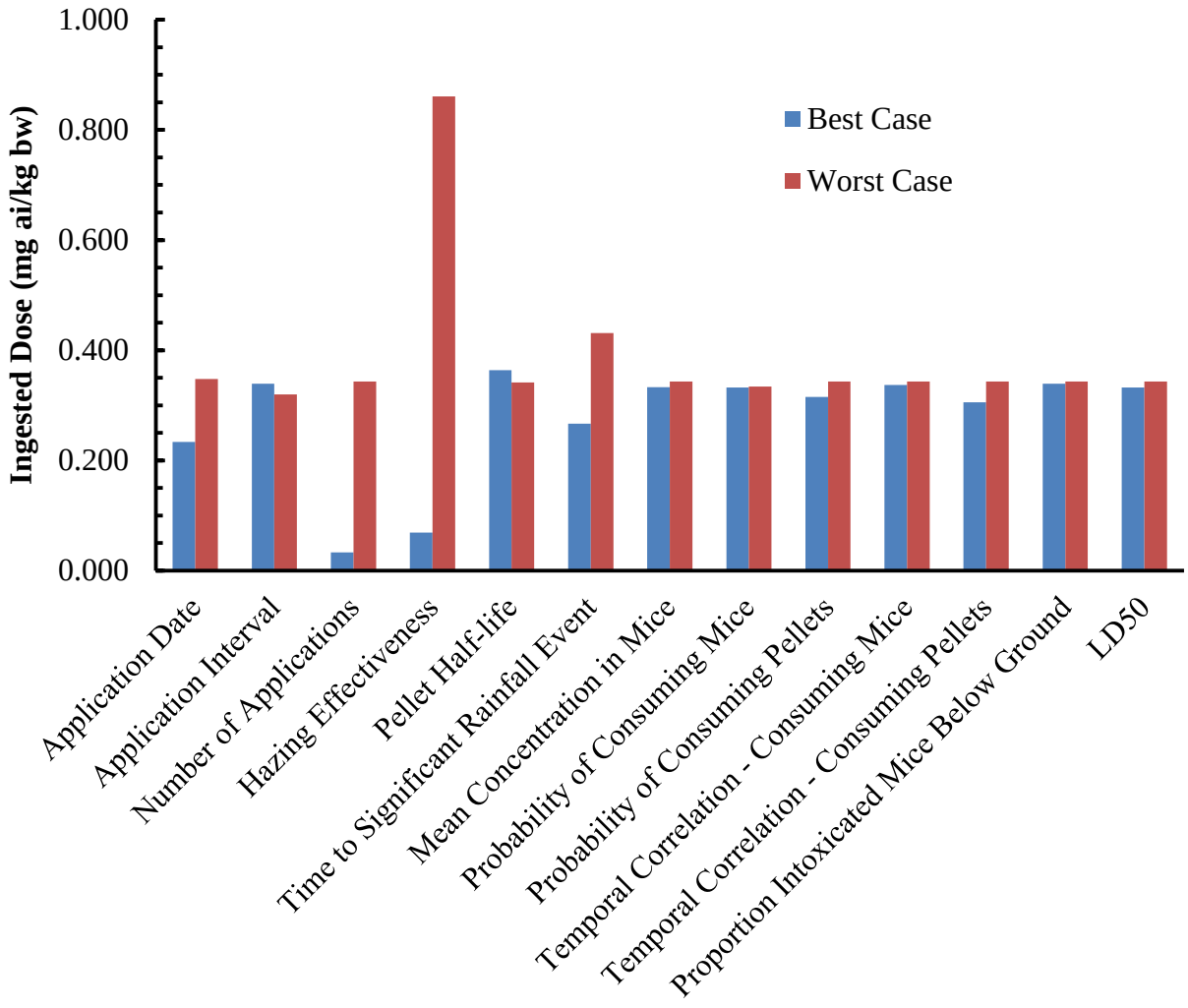

Figure 5-23. Results of sensitivity analysis for brodifacoum for maximum tissue concentration in western gulls exposed to brodifacoum.

The results of the sensitivity analysis for proportion and number of gulls dying were similar to the results for gull exposure

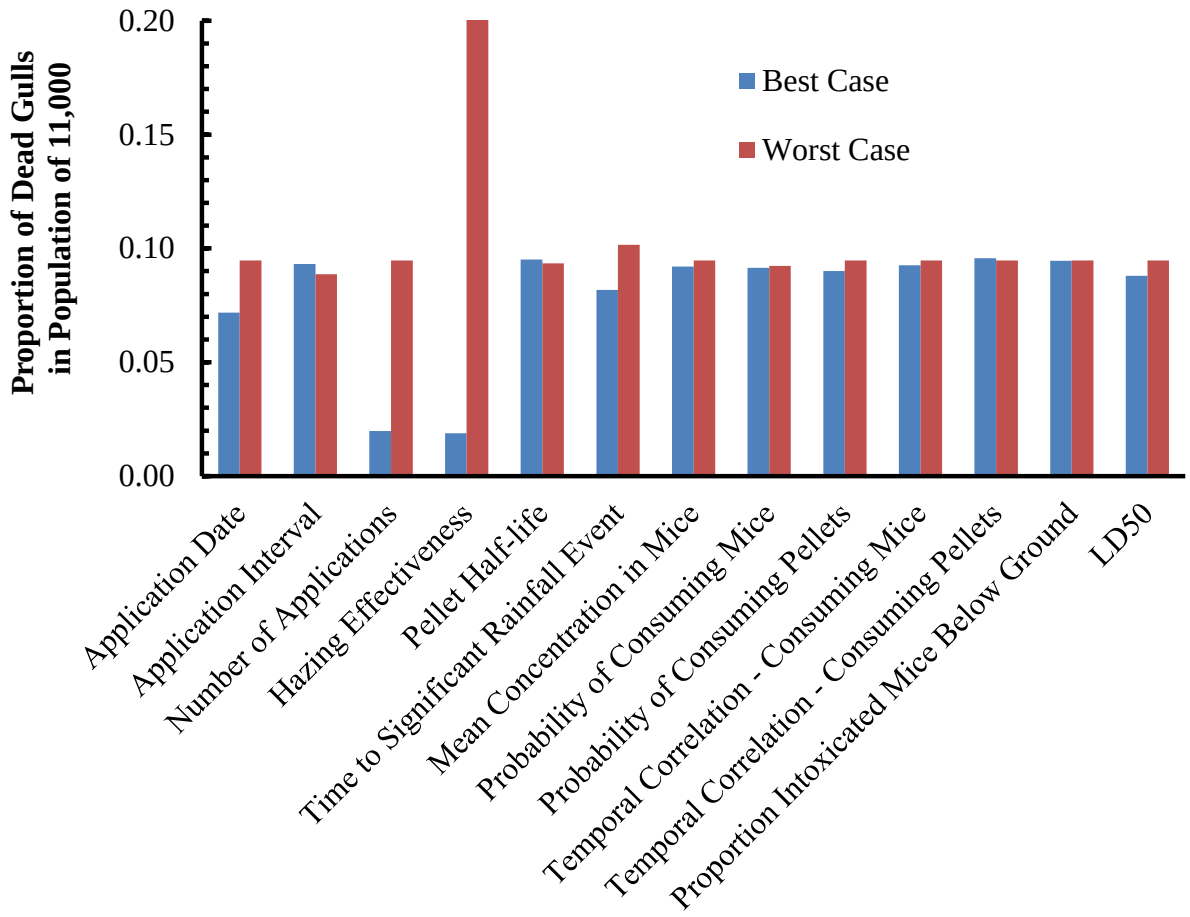

Figure 5-24. Results of sensitivity analysis for proportion of 11,000 western gulls dying from exposure to brodifacoum.

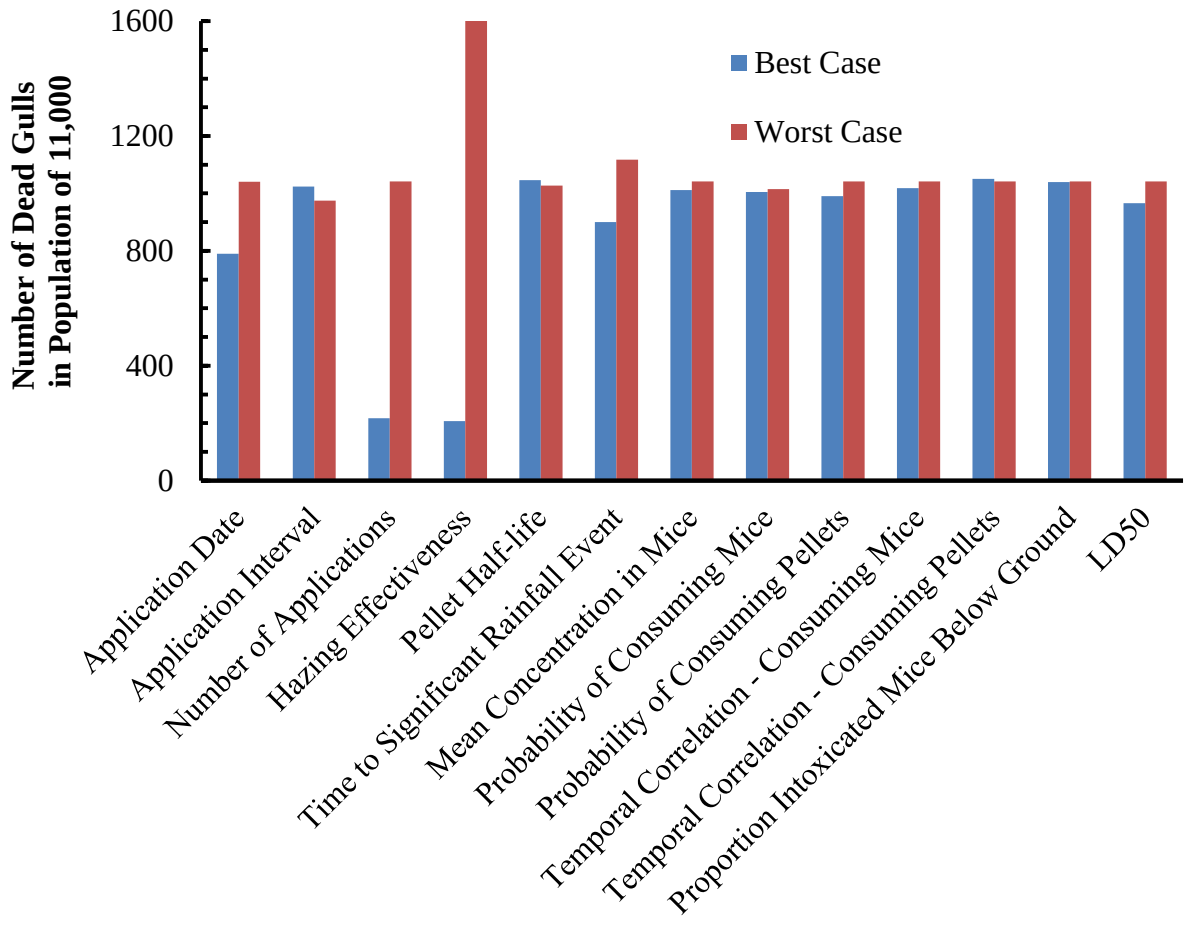

Figure 5-25. Results of sensitivity analysis for number of western gulls dying from exposure to brodifacoum.

5.4.2 Diphacinone

Figures 5-26 to 5-28 show the results of the sensitivity analyses for diphacinone for maximum tissue concentration, proportion mortality of gulls, and number of dead gulls. The results of the sensitivity analysis for diphacinone are highly similar to those for brodifacoum but with two notable differences. First, only one time (i.e., 98 days) was modeled for rainfall events. The second notable difference was the highly influential LD50 assumed for the analysis. No toxicity tests have been carried out on gull species for diphacinone. As a result, the sensitivity of western gulls to this rodenticide is unknown. Assuming the worst case LD50 of 0.82 mg ai/kg bw for screech owls (Rattner et al., 2012) led to predictions of significant mortality for western gulls (Figures 5-27 and 5-28). However, assuming the LD50 for American kestrels (97 mg ai/kg bw; Rattner et al., 2010) resulted in predictions of low mortality to western gulls. Conducting a

toxicity test specific for western gulls is recommended to reduce the uncertainty of using LD50 values from unrelated bird species.

As with brodifacoum, hazing effectiveness and the number of applications impacts gull exposure and mortality. One reason that gull impacts are greater with multiple applications of diphacinone is due to the cumulative nature of diphacinone exposure. That is, a lethal dose requires many days to weeks of constant ingestion because diphacinone is metabolized at the same time that it is being consumed.

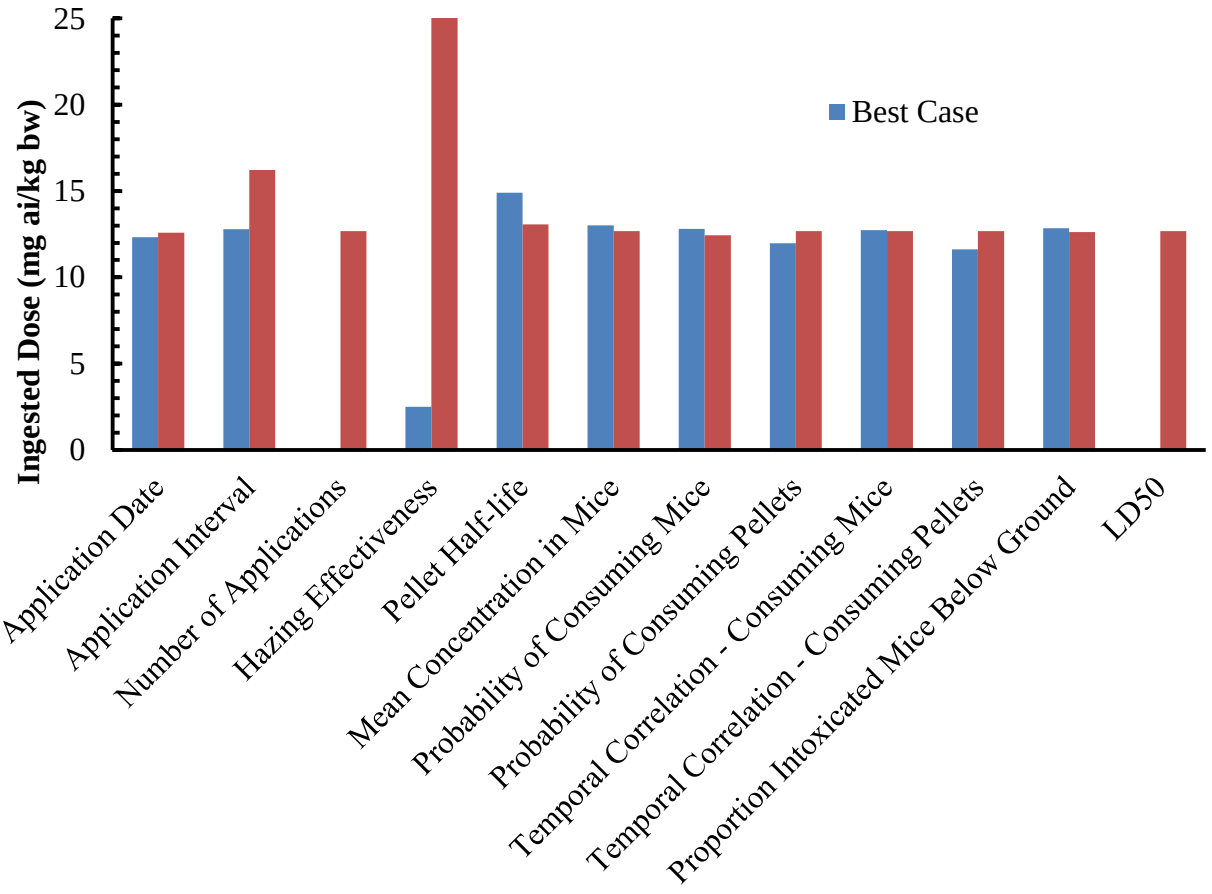

Figure 5-26. Results of sensitivity analysis for diphacinone for maximum tissue concentration in western gulls exposed to diphacinone.

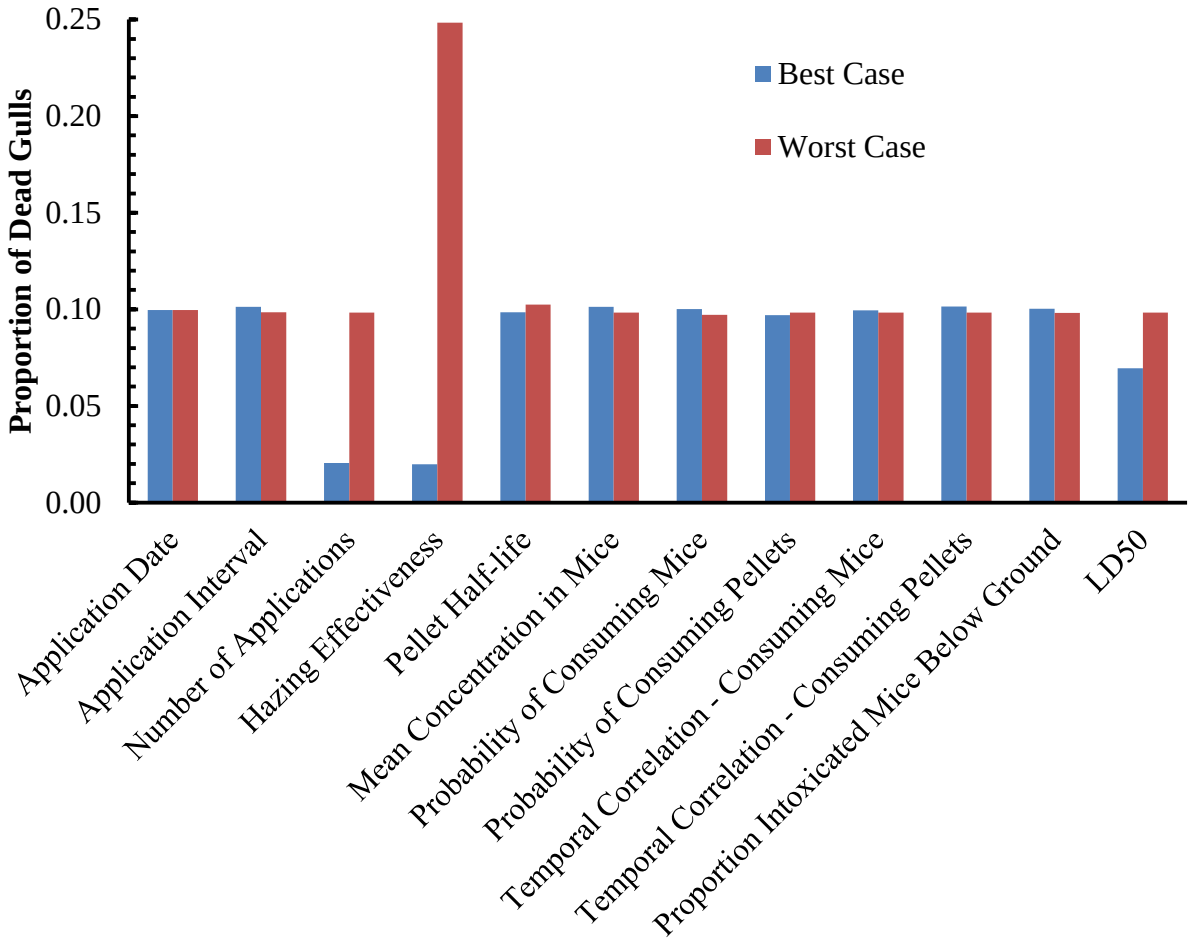

Figure 5-27. Results of sensitivity analysis for proportion of 11,000 western gulls dying from exposure to diphacinone.

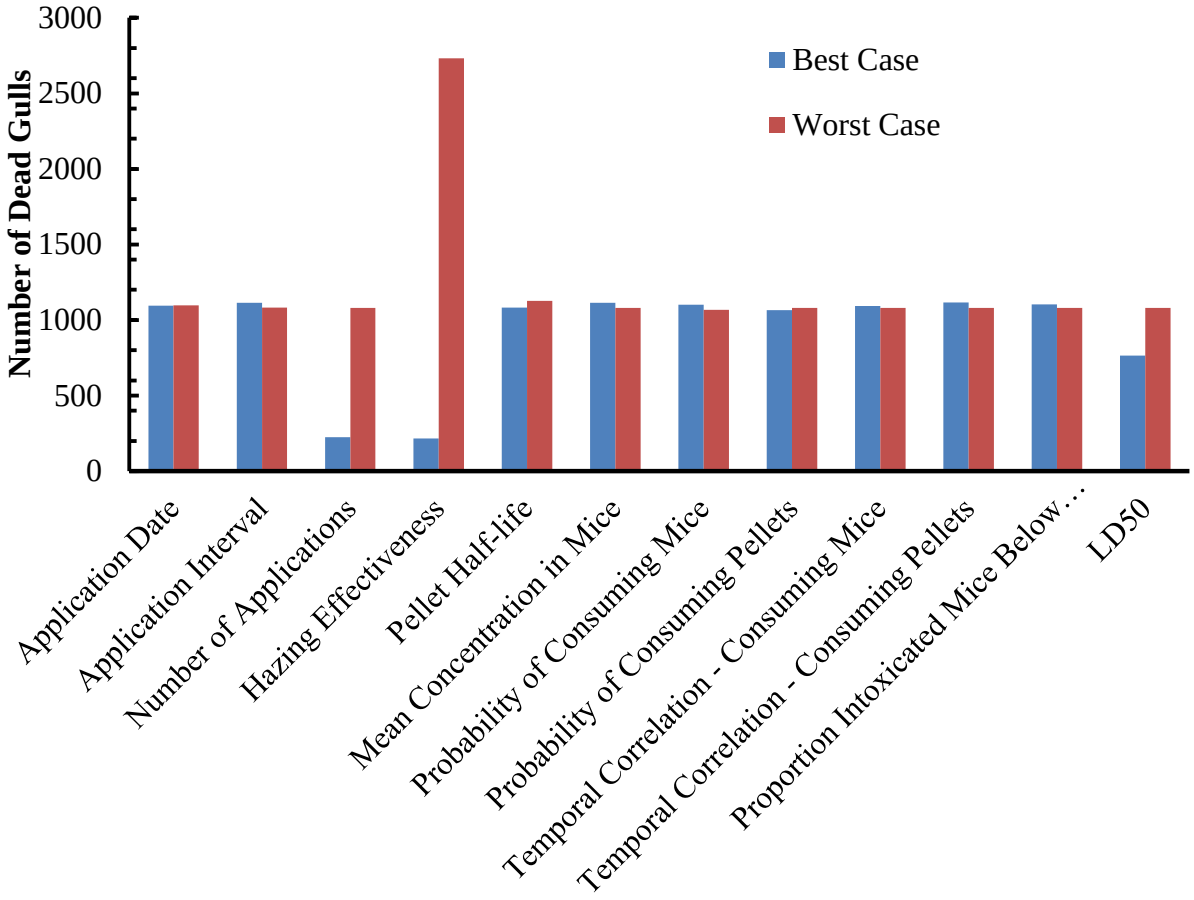

Figure 5-28. Results of sensitivity analysis for number of western gulls dying from exposure to diphacinone.

5.4.3 Data Gaps

Based on the results of the sensitivity analyses, we identified several data gaps for which more information would be beneficial to reduce uncertainty:

- Hazing effectiveness over extended (multi month) periods
- LD50s for western gull for brodifacoum and diphacinone
- Daily probability of western gulls ingesting pellets

In most other projects involving application of rodenticides, gull populations have not been significantly affected. For example, a western gull colony on Anacapa Island in southern California (approximately 10,300 breeding birds; Carter et al., 1992) was not significantly affected by a rat eradication project involving application of brodifacoum. In that project, there was a loss of only 2 gulls documented (Howald et al., 2004). Mortality of glaucous-winged gulls

was recorded on Rat Island after an aerial application of bait containing brodifacoum (Salmon and Paul, 2010), but no detectable change to the overall population was recorded and five years later the species is more abundant on the island (Newton et al., 2014). Eason et al. (2002) reported individual gull mortalities in relation to brodifacoum-based rodent eradication projects, but there were no significant population-level effects. In fact, there has never been a reported population-level effect to any gull species from a rodent eradication using rodenticide bait. A number of factors could explain the discrepancy between the predictions of the western gull risk model and the general lack of gull incidents with previous rat eradication projects:

- The western gull population on SFI is much larger than most gull populations on other islands, which increases the likelihood of gulls learning from each other on SFI versus other islands. It also increases the likelihood of higher gull mortalities.
- The lack of dense vegetation and the rocky substrate of SFI will render rodent bait more visible and accessible to gulls than on other islands.
- Other islands may have had more frequent rainfall events which led to rapid breakdown and removal of pellets. Time to a significant rainfall event after the second application is a key variable in the western gull risk model affecting predicted exposure of gulls.
- One or more assumptions in the western gull model could be incorrect. Data were limited on several key components of the model (e.g., hazing effectiveness, daily probabilities of consuming pellets, LD50s). Although the use of best and worst case values attempted to bracket the uncertainty, there clearly is a need to conduct additional research to reduce uncertainty where possible in the model.

In the event that additional research is carried out on key input parameters, the western gull risk model can be updated and additional runs undertaken to refine model predictions of mortality of western gulls on SFI.

5.5 COMPARISON OF EFFECTS OF BRODIFACOUM AND DIPHACINONE ON WESTERN GULL MORTALITY

One of the objectives of this assessment was to determine the relative risks of brodifacoum and diphacinone to western gulls on SFI. It is somewhat difficult to compare the results presented in Appendices A and B because both assessments were highly conservative and based on data with low certainty for some input variables. For example, the LD50s assumed for both compounds were based on species unrelated to western gulls (i.e., mallard and screech owl) and were highly conservative relative to other tested bird species (although gull species may be sensitive to these rodenticides). Also, information was not available on bait degradation for diphacinone during wet years.

The results from the western gull risk model clearly show that both chemicals pose risks at similar hazing efficiencies (Appendices A and B). If hazing success is 90% or higher, neither rodenticide is likely to cause 1700 or greater gull mortalities, given the model assumptions.

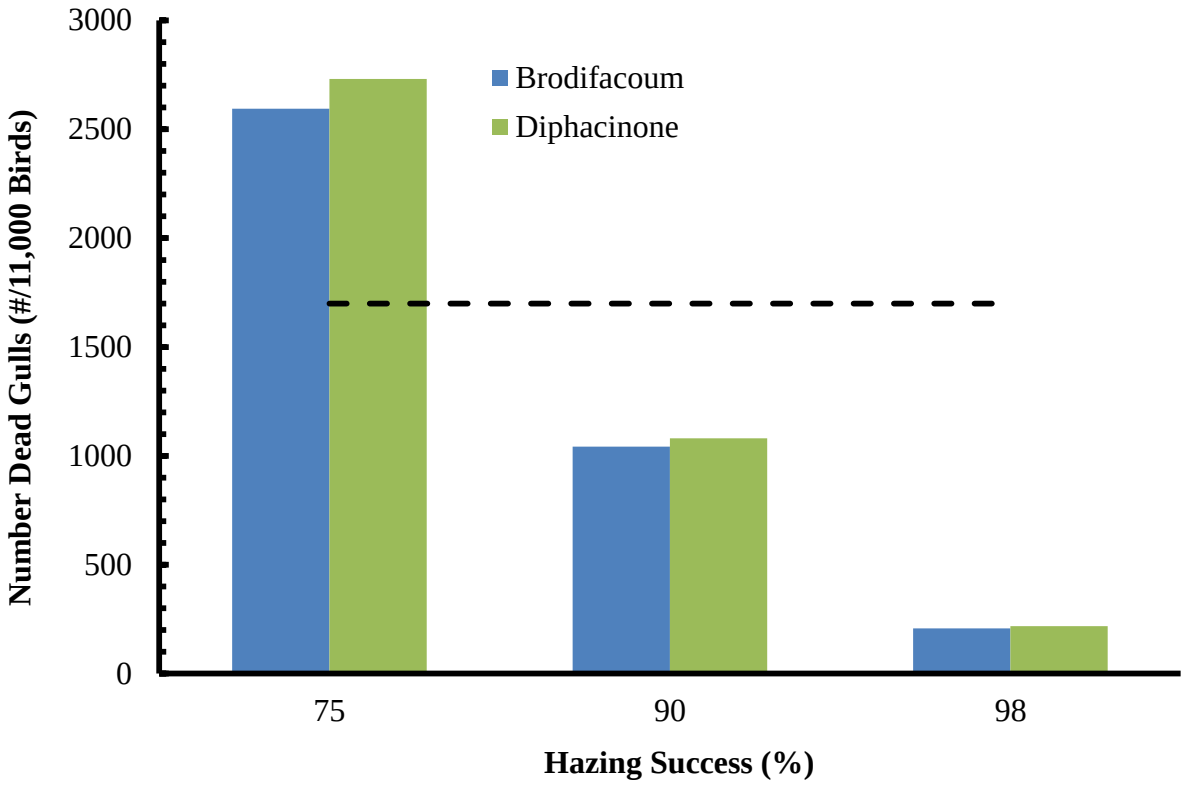

Figure 5-29. Effects of hazing success on predicted gull mortality for brodifacoum and diphacinone assuming an initial application date of November 29. The dashed line represents 1700 dead gulls.

6.0 CONCLUSIONS

The likelihoods of brodifacoum and diphacinone applications achieving total eradication of mice on SFI were not considered in this assessment. Based on the model results, both brodifacoum and diphacinone pose risks to unhazed western gulls. To most effectively reduce gull mortalities, it would be advisable to consider implementing an effective gull hazing program, an early start date, and other measures to reduce gull exposure to bait, including some use of bait stations or possibly hand removal of bait pellets after several weeks, if any remain. Because the western gull risk model used conservative input parameters when exact values were unknown, it is likely that the model overestimated expected gull mortalities. Further, several important parameters that could affect uptake of rodenticide by gulls were not included in the model. For example plant cover increases rapidly shortly after the first significant rainfall of the season, usually in November or December. High plant cover hid many placebo bait pellets in trials conducted in early December 2012 (Grout & Griffiths 2012). If seasonal plant cover is high by the time of application or shortly thereafter, gulls could have more trouble locating pellets, thus reducing exposure. Similarly, use of bait stations in some areas (e.g., where terrain is relatively flat and accessible) would reduce gull exposure. Use of bait stations on portions of SFI was not included in the model.

7.0 REFERENCES

Ainley, D.G. and T.J. Lewis. 1974. The history of Farallon Island marine bird populations 1843-1972. *Condor*, 76:432-446.

Ainley, D.G., C.S. Strong, T.M. Penniman and R.J. Boekelheide. 1990. The feeding ecology of Farallon seabirds. In: D.G. Ainley and R.J. Boekelheide, Eds, Seabirds of the Farallon Islands: Ecology, Dynamics, and Structure of an Upwelling System Community. Stanford University Press, Palo Alto, CA.

Annett, C.A. and R. Pierotti. 1989. Chick hatching as a trigger for dietary switches in western gulls. *Colonial Waterbirds*, 12:4-11.

Ashton, A.D., W.B. Jackson and H. Peters. 1987. Comparative evaluation of LD50 values for various anticoagulant rodenticides. In: Control of Mammal Pests, Eds, C.G.J Richards and T.Y. Ku. Taylor and Francis, London, U.K. pp. 187-198.

Bowie, M.H. and J.G. Ross. 2006. Identification of weta foraging on brodifacoum bait and the risk of secondary poisoning for birds on Quail Island, Canterbury, New Zealand. New Zealand *Journal of Ecology*, 30:219-228.

Buckelew, S., G.R. Howald, A. Wegmann, J. Sheppard, J. Curl, P. McClelland, B. Tershy, K. Swift, E. Campbell and B. Flint. 2005. Progress in Palmyra Atoll restoration: Rat eradication trial 2005. Report to the US Fish and Wildlife Service by Island Conservation, Santa Cruz, CA.

Buckelew, S., G. Howald, S. MacLean, S. Ebbert and T.M. Primus. 2008. Progress in restoration of the Aleutian Islands: Trial rat eradication, Bay of Islands, Adak, Alaska, 2006. Report to the US Fish and Wildlife Service by Island Conservation, Santa Cruz, CA.

Campbell, S., K.A. Hoxster and G. J. Smith. 1991. Diphacinone technical: An acute oral toxicity study with northern bobwhite. Wildlife International, Easton, MD. Project No. 284-103. Submitted by Bell Laboratories, Inc., Madison WI. EPA MRID 422452-01.

Carter, H.R., G.J. McChesney, D.L. Jaques, C.S. Strong, M.W. Parker, J. E. Takekawa, D.L. Jory, and D.L. Whitworth. 1992. Breeding populations of seabirds in California, 1989-1991. Vols 1 and 2. Unpublished draft final report, U.S. Fish and Wildlife Service, Northern Prairie Wildlife Research Center, Dixon, California.

Chipman, R.B., R.A. Dolbeer, K.J. Preusser, D.P. Sullivan, E.D. Losito, A.L. Gosser and T.W. Seamans. 2004. Emergency wildlife management response to protect evidence associated with the terrorist attack on the World Trade Center, New York City. *Proceedings of the 21st Vertebrate Pest Conference*, 21:281-286.

Cotter, S.C. 1979. A screening design for factorial experiments with interactions. *Biometrika*, 66:317-320.

Curtis, P.D., C.R. Smith and W. Evans. 1995. Techniques for reducing bird use at Nanticoke landfill near E.A. Link Airport, Broome County, New York. *Sixth Eastern Wildlife Damage Control Conference*, 6:67-78.

Daltry, J.C. 2006. Control of the black rat *Rattus rattus* for the conservation of the Antiguan racer *Alsophis antiguae* on Great Bird Island, Antigua. *Conservation Evidence*, 3:28-29.

Eason, C.T., E.C. Murphy, G.R.G. Wright and E.B. Spurr. 2002. Assessment of risks of brodifacoum to non-target birds and mammals in New Zealand. *Ecotoxicology*, 11:35-48.

Ebbert, S., A. Sowls and V. Byrd. 2007. Alaska's rat spill response program. In: Managing Vertebrate Invasive Species Proceedings of an International Symposium. USDA, APHIS, WS, National Wildlife Research Center, Fort Collins, Colorado, USA. pages 3332–3337.

ECOFRAM (Ecological Committee on FIFRA Risk Assessment Methods). 1999. Terrestrial Draft Report. http://www.epa.gov/oppefed1/ecorisk/terrreport.pdf

EPA (United States Environmental Protection Agency). 1993. Wildlife Exposure Factors Handbook. Office of Research and Development, Washington, DC. EPA/600/R-93/187a.

EPA (United States Environmental Protection Agency). 1998a. Reregistration Eligibility Decision (RED): Rodenticide Cluster. Office of Prevention, Pesticides and Toxic Substances, Office of Pesticide Programs, Washington, D.C. EPA738-R-98- 007.

EPA (United States Environmental Protection Agency). 1998b. Guidelines for Ecological Risk Assessment. Risk Assessment Forum, Washington, D.C. EPA/630/R-95/002F.

EPA (United States Environmental Protection Agency). 2004. Overview of the Ecological Risk Assessment Process in the Office of Pesticide Programs, U.S. Environmental Protection Agency: Endangered and Threatened Species Effects Determination. Office of Prevention, Pesticides and Toxic Substances, Office of Pesticide Programs, Washington, D.C.

EPA (United States Environmental Protection Agency). 2008. Pesticide Product Label, Brodifacoum-25D Conservation. Office of Prevention, Pesticides and Toxic Substances, Office of Pesticide Programs, Washington, D.C. EPA Reg. No. 56228-37.

EPA (United States Environmental Protection Agency). 2011. Risks of Diphacinone Use to the Federally Threatened Alameda Whipsnake (*Masticophis lateralis euryxanthus*), California Tiger Salamander (*Ambystoma californiense*), and the Federally Endangered Salt Marsh Harvest Mouse, California Tiger Salamander (*Ambystoma californiense*) Sonoma County Distinct Population Segment and Santa Barbara County Distinct Population Segment, and San Joaquin

Kit Fox (*Vulpes macrotis mutica*). Office of Prevention, Pesticides and Toxic Substances, Office of Pesticide Programs, Washington, D.C.

Erickson, W. and D. Urban. 2004. Potential Risks of Nine Rodenticides to Birds and Nontarget Mammals: A Comparative Approach. Office of Prevention, Pesticides and Toxic Substances, Office of Pesticide Programs, Washington, D.C.

Fisher, P.M. 2009. Residual Concentrations and Persistence of the Anticoagulant Pesticides Brodifacoum and Diphacinone in Fauna. Ph.D. Thesis, Lincoln University, Lincoln, New Zealand.

Fisher, P.M. 2010. Environmental fate and residual persistence of brodifacoum in wildlife. *Envirolink,* 884-HBRC131.

Fisher, P.M., R. Griffiths, C. Speedy and K. Broome. 2011. Environmental monitoring for brodifacoum residues after aerial application of baits for rodent eradication. *In:* Veitch, C.R., M.N. Clout and D.R. Towns (eds.), Island Invasives: Eradication and Management, pp. 300-304. IUCN, Gland, Switzerland.

FWS (United States Fish and Wildlife Service). 2007. Restoring Wildlife Habitat on Rat Island: Environmental Assessment. Alaska Maritime National Wildlife Refuge, Aleutian Islands Unit, Homer, AK. 152pp.

FWS (United States Fish and Wildlife Service). 2012. House mouse eradication from the South Farallon Islands: Draft environmental impact statement. San Francisco Bay National Wildlife Refuge Complex, Newark, CA.

Godfrey, M.E.R. 1985. Non-target and secondary poisoning hazards of "second generation" anticoagulants. *Acta Zoologica Fennica,* 173:209-212.

Godfrey, M.E.R. 1986. An evaluation of the acute-oral toxicity of brodifacoum to birds. Proceedings of the Vertebrates Pesticides Conference, 12:78-81.

Griffiths, R. and D. Towns. 2008. The Rangitoto and Motutapu pest eradication – A feasibility study. Department of Conservation, Wellington, New Zealand.

Griffiths, R., D. Grout and N. Holmes. 2013. Farallon Islands Restoration Project: Evaluating the Duration of Potential Risk Exposure to Susceptible Non-target Species Following Application of Rodent Bait. Island Conservation, Santa Cruz, CA. 15pp.

Grout, D. 2012. Report of the 2010 mouse removal field trial on the Farallon Islands. Unpublished Report for the U.S. Fish and Wildlife Service.

Grout, D. and R. Griffiths. 2012. Farallon Islands Restoration Project – A Report on Trials Undertaken to Inform Project Feasibility and Non-target Risk Assessments. Island Conservation, Santa Cruz, CA.

Howald, G.R. 1997. The risk of non-target species poisoning from brodifacoum used to eradicate rats from Langara Island, British Columbia, Canada. M.Sc. Thesis. University of British Columbia, Vancouver, BC. 159 pp.

Howald, G.R., J.C. Donlan, K.R. Faulkner, S. Ortega, S., H. Gellerman, D.A. Croll and B.R. Tershy. 2009. Eradication of black rats *Rattus rattus* from Anacapa Island. *Oryx*, 44:30-40.

Howald, G., C. Donlan, J. Galvan, J. Russel, J. Parkes, A. Samaniego, Y. Wand, D. Veitch, P. Genovesi, M. Pascal, A. Saunders and B. Tershy. 2007. Invasive rodent eradication on islands. *Conservation Biology*, 21:121-124.

Howald, G.R., P. Mineau, J.E. Elliott and K.M. Cheng, K.M. 1999. Brodifacoum poisoning of avian scavengers during rat control on a seabird colony. *Ecotoxicology*, 8:431-447.

Howald, G.R., A. Samaniego, S. Buckalew, P. McClelland, B. Keitt, A. Wegmann, W.C. Pitt, D.S. Vice, E. Campbell, K. Swift and S. Barclay. 2004. Palmyra Atoll rat eradication assessment trip report August 2004. Unpublished report.

Howald, G.R., B.R. Tershy, B.S. Keitt, H. Gellerman, S. Ortega, K. Faulkner, C.J. Donlan and D.A. Croll. 2001. Progress in rat eradication, Anacapa Island, Channel Islands National Park, California. Unpublished report submitted to United States Environmental Protection Agency by the National Park Service, United States Department of the Interior, Washington, DC.

Hunt, G.L. and J.L. Butler. 1980. Reproductive ecology of western gulls and Xantus' murrelets with respect to food resources in the Southern California Bight. CalCOFI Report, Volume XXI.

Hunt, G.L. and M.W. Hunt. 1976. Exploitation of fluctuating food resources by western gulls. *Auk*, 93:301-307.

ICWDM (Internet Center for Wildlife Damage Management). 2005. Description of Active Ingredients. Accessed online at: http://icwdm.org/handbook/pestchem/active.asp

Imber, M., M. Harrison and J. Harrison. 2000) Interactions between petrels, rats and rabbits on Whale Island, and effects of rat and rabbit eradication. *New Zealand Journal of Ecology*, 24:153-160.

Keitt, B., K. Campbell, A. Saunders, M. Clout, Y. Wang, R. Heinz, K. Newton and B. Tershy. 2011. The Global Islands Invasive Vertebrate Eradication Database: A tool to improve and facilitate restoration of island ecosystems. In: C.R.Veitch, M.N. Clout and D.R. Towns, Eds, Island Invasives: Eradication and Management. IUCN, Gland, Switzerland. Pages 74-77.

Knopper, L.D., P. Mineau, L.A. Walker and R.F. Shore. 2007. Bone density and breaking strength in UK raptors exposed to second generation anticoagulant rodenticides. *Bulletin of Environmental Contamination and Toxicology,* 78:249-251.

Long, R., J. Foster, K. Hoxter, et al. 1992. Diphacinone technical: A dietary LC50 study with the mallard. Wildlife International, Ltd., Easton, MD. Project No. 284-102B.

Macdonald, D.W. and M.G. Fenn. 1994. The natural history of rodents: Preadaptations to pestilence. In: A.P. Buckle and R.H. Smith, Eds, Rodents Pests and Their Control. CAB International, Wallingford, U.K. Pages 1-21.

Mackay J.W.B., J.C. Russell and E.C. Murphy. 2007. Eradicating house mice from islands: Successes, failures and the way forward. In: G.W. Witmer, W.C. Pitt and K.A. Fagerstone, Eds, Managing Vertebrate Invasive Species: Proceedings of an International Symposium. National Wildlife Research Center, Fort Collins, CO.

Mendenhall, V.M. and L.F. Pank. 1980. Secondary poisoning of owls by anticoagulant rodenticides. *Wildlife Society Bulletin*, 8:311-315.

Merton, D. 1987. Eradication of rabbits from Round Island, Mauritius: A conservation success story. *Dodo, Journal of Jersey Wildlife Preservation Trust*, 24:19-43

Mineau, P., S. Trudeau, L.D. Knopper, J. Smits, S.P. Gallagher, J.B. Beavers and J.B. Jaber. 2005. Consequences in birds of sub lethal exposure to second generation anti-coagulant rodenticides. 26th Annual SETAC North America Meeting, Baltimore, MD.

Morgan, D.R. and G.R. Wright. 1996. Environmental effects of rodent Talon baiting: Part I. Monitoring for toxic residues. *Science for Conservation*, 38:5-11.

Mosher, S., A. Hebshi, K. Swift, P. Dunlevy, D. Vice, A. Wegmann, B. Jacobs, P. McClelland, B. Thomas, K. Mate Traps and J. Gilardi. 2007. Rat eradication feasibility study 29 September - 27 October 2007. Draft report summarizing the work conducted to determine the feasibility and approach for a full eradication of rats from Wake Atoll.

Musser, G.G. and M.D. Carleton. 2005. Superfamily Muroidea. In: Wilson, D.E. and D.M. Reeder, Eds, Mammal Species of the World: A Taxonomic and Geographic Reference, 3rd edition. The Johns Hopkins University Press, Baltimore, MD. pages 894–1531.

Nagy, K.A. 1987. Field metabolic rate and food requirements scaling in mammals and birds. *Ecological Monographs*, 57:111-128.

Newton, K.M., M. McKown and D.A. Croll. 2014. Five Year Post Rat Eradication Monitoring Report: Hawadax (formerly Rat) Island, Aleutian Archipelago, Alaska. Report to Island Conservation, Santa Cruz, CA.

Nur, N., R.W. Bradley, D.E. Lee, P.M. Warzybok and J. Jahncke. 2012. Population Viability Analysis of Western Gulls on the Farallon Islands in Relation to Potential Mortality Due to Proposed House Mouse Eradication. Unpublished report to the US Fish and Wildlife Service. PRBO Conservation Science, Petaluma, California. PRBO Contribution Number 1868.

Ogilvie, S.C., R.J. Pierce, G.R.G. Wright, L.H. Booth and C.T. Eason. 1997. Brodifacoum residue analysis in water, soil, invertebrates, and birds after rat eradication on Lady Alice Island. *New Zealand Journal of Ecology*, 21:195-197.

Parkes, J., P. Fisher and G. Forrester. 2011. Diagnosing the cause of failure to eradicate introduced rodents on islands: brodifacoum versus diphacinone and method of bait delivery. *Conservation Evidence*, 8: 100-106.

Penniman, T.M., M.C. Coulter, L.B. Spear and R.J. Boekelheide. 1990. Western gull. In: D.G. Ainley and R.J. Boelkelheide, Eds, Seabirds of the Farallon Islands: Ecology, Dynamics and Structure of an Upwelling System Community. Stanford University Press, Palo Alta, CA. Pages 218-244.

Pierotti, R. 1976. Sex roles, social structure, and the role of the environment in the western gull. Master's thesis, California State University, Sacramento, CA.

Pierotti, R. 1980. Spite and altruism in gulls. *American Naturalist*, 115:290-300.

Pierotti, R. 1981. Male and female parental roles in the western gull under different environmental conditions. *Auk*, 98:532-549.

Pierotti, R. and C.A. Annett, 1991. Diet choice in the herring gull: Effects of constraints imposed by reproduction and ecology. *Ecology*, 72:319-328.

Pierotti, R.J. and C.A. Annett. 1995. Western gull (*Larus occidentalis*). In: A. Poole, Ed, The Birds of North America Online. Cornell Lab of Ornithology, Ithaca, NY. http://bna.birds.cornell.edu/bna/species/174

Pitt, W.C., L.C. Driscoll and R.T. Sugihara. 2011. Efficacy of rodenticide baits for the control of three invasive rodent species in Hawaii. *Archives of Environmental Contamination and Toxicology*, 60:533-542.

Pott, M, and D. Grout. 2012. Results of a pilot gull hazing trial on the Farallon National Wildlife Refuge. Island Conservation, Santa Cruz, CA.

Rattner, B.A., K.E. Horak, R. S. Lazarus, K.M. Eisenreich, C.U. Meteyer, S.F. Volker, C.M. Campton, J.D. Eisemann and J.J. Johnston. 2012. Assessment of toxicity and potential risk of the anticoagulant rodenticide diphacinone using Eastern screech-owls (*Megascops asio*). *Ecotoxicology*, 21:832-846.

Rattner, B.A., K.E. Horak, S.E. Warner, D.D. Day and J.J. Johnston. 2010. Comparative toxicity of diphacinone to northern bobwhite (*Colinus virginianus*) and American kestrels (*Falco sparverius*). *Proceedings of the 24th Vertebrate Pest Conference*, 24:146-152.

Rattner, B.A., K.E. Horak, S.E. Warner, D.D. Day, C.U. Meteyer, S.F. Volker, J.D. Eisemann and J.J. Johnston. 2011. Acute toxicity, histopathology, and coagulopathy in American kestrels (*Falco sparverius*) following administration of the rodenticide diphacinone. *Environmental Toxicology and Chemistry*, 30:1213-1222.

Salmon, T. and E. Paul. 2010. The Rat Island Eradication Project: A Critical Evaluation of Non-target Mortality. The Ornithology Council, Bethesda, MD.

Samaniego-Herrera, A., A. Aguirre-Muñoz, G. Howald, M. Felix-Lizarraga, J. Valdez-Villavicencio, R. Gonzalez-Gomez, F. Mendez-Sanchez, F. Torres-Garcia, M. Rodríguez-Malagón, and B. Tershy. 2009. Eradication of black rats from Farallon de San Ignacio and San Pedro Martir Islands, Gulf of California, Mexico. In: Proceedings of the 7th California Islands Symposium. Institute for Wildlife Studies, Arcata, CA. Pages 337-347.

Slate, D., J. McConnell, M. Barden, R. Chipman, J. Janicke and C. Benuy. 2000. Controlling gulls at landfills. *Proceedings of the 19th Vertebrate Pest Conference*, 19:68-76.

Snellen, C.L., P.J. Hodum and E. Fernandez-Juricic. 2007. Assessing western gull predation on purple sea urchins in the rocky intertidal using optimal foraging theory. *Canadian Journal of Zoology*, 85:221-231.

Sowls, A.L., A.R. Degange, J.W. Nelson and G.S. Lester. 1980. Catalog of California seabird colonies. United States Fish and Wildlife Service, Slidell, LA. FWS/OBS 80/37.

Spear, L.B. 1988. Dispersal patterns of western gulls from Southeast Farallon Island. *Auk*, 105:128-141.

Stone, W.B., J.C. Okoniewski and J.R. Stedelin. 1999. Poisoning of wildlife with anticoagulant rodenticides in New York. *Journal of Wildlife Diseases*, 35:187-193.

Suter, G.W., L.W. Barnthouse, S.M. Bartell, T. Mill, D. Mackay and S. Patterson. Ecological Risk Assessment. Lewis Publishers, Chelsea, MI.

Taylor, R.H. 1993. The feasibility of rat eradication on Langara Island, British Columbia, Canada. Report to the Canadian Wildlife Service, Ottawa, ON. 30 pp.

Taylor, R.H. and B.W. Thomas. 1989. Eradication of Norway rats (*Rattus norvegicus*) from Hawea Island, Fiordland, using brodifacoum. *New Zealand Journal of Ecology*, 12:23-32.

Taylor, R.H. and B.W. Thomas. 1993. Rats eradicated from rugged Breaksea Island (170 ha), Fiordland, New Zealand. *Biological Conservation*, 65:191-198.

Vyas, N.B. and B.A. Rattner. 2012. Critique on the use of the standardized avian acute oral toxicity test for first generation anticoagulant rodenticides. *Human and Ecological Risk Assessment,* 18:1069-1077.

Wanless, R.M., P. Fisher, J. Cooper, J. Parkes, P.G. Ryan and M. Slabber. 2008. Bait acceptance by house mice: An island field trial. *Wildlife Research,* 35:806-811.

Warzybok, P., R. Bradley, D. Grout, R. Griffiths, M. Pott, W. Vickers, D. Milsaps and G. McChesney. 2013. Evaluating the Use of Non-lethal Hazing Techniques to Minimize Potential Exposure of Western Gulls to Rodenticide from a Proposed Rodent Eradication on the South Farallon Islands. Island Conservation, Santa Cruz, CA.

Weber, P. 2001. Vitamin K and bone health. *Nutrition*, 17:880-887.

Wildlife International. 1979a. Forty-day LC50 - Laughing Gull, Technical Brodifacoum, Final Report. Submitted to ICI Americas, Inc., Goldsboro, NC. Submitted by Wildlife International, Inc., Easton, MD.

Wildlife International. 1979b. Forty-day Dietary LC50 - Laughing Gull, Masticated Rodent Tissue Containing PP581, Final Report. Submitted to ICI Americas, Inc., Goldsboro, NC. Submitted by Wildlife International, Inc., Easton, MD.

Witmer, G., J.D. Eisemann and G. Howald. 2007. The Use of Rodenticides for Conservation Efforts. In: D.L. Nolte, W.M. Arjo and D.H. Stalman, Eds, *Proceedings of the 12th Wildlife Damage Management Conference,* 12: 160-167.

World Health Organization. 1995. Anticoagulant rodenticides. World Health Organization, Geneva, Switzerland. Environmental Health Criteria 175.

APPENDIX A – MODELING RESULTS FOR WESTERN GULLS EXPOSED TO BRODIFACOUM ON THE FARALLON ISLANDS

Date of Application	Proportion of Gulls Removed by Hazing	Time to Significant Rainfall Event (d)	Number of Applications	Dead Mice Removed?	Mean Total Ingested Dose (mg ai/kg bw)	Proportion of Dead Gulls	Number of Dead Gulls (#/11,000 Gulls)
Nov 1	0.75	14	2	No	0.136	0.0431	474
Nov 8	0.75	14	2	No	0.369	0.121	1331
Nov 15	0.75	14	2	No	0.446	0.138	1516
Nov 22	0.75	14	2	No	0.589	0.187	2061
Nov 29	0.75	14	2	No	0.647	0.202	2221
Dec 6	0.75	14	2	No	0.654	0.203	2229
Dec 13	0.75	14	2	No	0.676	0.211	2319
Dec 20	0.75	14	2	No	0.674	0.210	2308
Nov 1	0.9	14	2	No	0.057	0.0184	202
Nov 8	0.9	14	2	No	0.141	0.0465	511
Nov 15	0.9	14	2	No	0.171	0.0540	594
Nov 22	0.9	14	2	No	0.236	0.0736	809
Nov 29	0.9	14	2	No	0.267	0.0818	900
Dec 6	0.9	14	2	No	0.264	0.0811	892
Dec 13	0.9	14	2	No	0.278	0.0860	945
Dec 20	0.9	14	2	No	0.262	0.0827	909
Nov 1	0.95	14	2	No	0.0294	0.00927	101
Nov 8	0.95	14	2	No	0.0765	0.0249	273
Nov 15	0.95	14	2	No	0.0876	0.0276	303
Nov 22	0.95	14	2	No	0.121	0.0382	420
Nov 29	0.95	14	2	No	0.127	0.0396	435

Date of Application	Proportion of Gulls Removed by Hazing	Time to Significant Rainfall Event (d)	Number of Applications	Dead Mice Removed?	Mean Total Ingested Dose (mg ai/kg bw)	Proportion of Dead Gulls	Number of Dead Gulls (#/11,000 Gulls)
Dec 6	0.95	14	2	No	0.129	0.0403	442
Dec 13	0.95	14	2	No	0.130	0.0409	449
Dec 20	0.95	14	2	No	0.132	0.0418	460
Nov 1	0.98	14	2	No	0.0131	0.00390	42
Nov 8	0.98	14	2	No	0.0279	0.00913	100
Nov 15	0.98	14	2	No	0.0364	0.0110	121
Nov 22	0.98	14	2	No	0.0483	0.0150	165
Nov 29	0.98	14	2	No	0.0499	0.0159	174
Dec 6	0.98	14	2	No	0.0543	0.0169	186
Dec 13	0.98	14	2	No	0.0527	0.0165	181
Dec 20	0.98	14	2	No	0.0544	0.0169	185
Nov 1	0.75	30	2	No	0.586	0.182	2002
Nov 8	0.75	30	2	No	0.706	0.207	2275
Nov 15	0.75	30	2	No	0.778	0.221	2425
Nov 22	0.75	30	2	No	0.811	0.226	2488
Nov 29	0.75	30	2	No	0.861	0.236	2594
Dec 6	0.75	30	2	No	0.849	0.233	2565
Dec 13	0.75	30	2	No	0.852	0.235	2580
Dec 20	0.75	30	2	No	0.865	0.237	2611
Nov 1	0.9	30	2	No	0.234	0.0718	790
Nov 8	0.9	30	2	No	0.285	0.0844	928
Nov 15	0.9	30	2	No	0.316	0.0899	988
Nov 22	0.9	30	2	No	0.331	0.0922	1014
Nov 29	0.9	30	2	No	0.343	0.0947	1042
Dec 6	0.9	30	2	No	0.341	0.0933	1025

Date of Application	Proportion of Gulls Removed by Hazing	Time to Significant Rainfall Event (d)	Number of Applications	Dead Mice Removed?	Mean Total Ingested Dose (mg ai/kg bw)	Proportion of Dead Gulls	Number of Dead Gulls (#/11,000 Gulls)
Dec 13	0.9	30	2	No	0.336	0.0928	1020
Dec 20	0.9	30	2	No	0.348	0.0947	1041
Nov 1	0.95	30	2	No	0.115	0.0357	393
Nov 8	0.95	30	2	No	0.142	0.0416	457
Nov 15	0.95	30	2	No	0.152	0.0432	475
Nov 22	0.95	30	2	No	0.163	0.0452	496
Nov 29	0.95	30	2	No	0.167	0.0459	504
Dec 6	0.95	30	2	No	0.169	0.0461	507
Dec 13	0.95	30	2	No	0.166	0.0456	501
Dec 20	0.95	30	2	No	0.173	0.0479	527
Nov 1	0.98	30	2	No	0.0486	0.0149	163
Nov 8	0.98	30	2	No	0.0610	0.0182	200
Nov 15	0.98	30	2	No	0.0579	0.0166	182
Nov 22	0.98	30	2	No	0.0712	0.0200	220
Nov 29	0.98	30	2	No	0.0690	0.0189	207
Dec 6	0.98	30	2	No	0.0657	0.0180	198
Dec 13	0.98	30	2	No	0.0643	0.0174	191
Dec 20	0.98	30	2	No	0.0698	0.0190	209
Nov 1	0.75	99	2	No	1.02	0.248	2725
Nov 8	0.75	99	2	No	1.05	0.252	2772
Nov 15	0.75	99	2	No	1.04	0.245	2696
Nov 22	0.75	99	2	No	1.05	0.249	2743
Nov 29	0.75	99	2	No	1.05	0.248	2730
Dec 6	0.75	99	2	No	1.03	0.243	2678
Dec 13	0.75	99	2	No	1.03	0.246	2702

Date of Application	Proportion of Gulls Removed by Hazing	Time to Significant Rainfall Event (d)	Number of Applications	Dead Mice Removed?	Mean Total Ingested Dose (mg ai/kg bw)	Proportion of Dead Gulls	Number of Dead Gulls (#/11,000 Gulls)
Dec 20	0.75	99	2	No	1.03	0.247	2719
Nov 1	0.9	99	2	No	0.409	0.0990	1089
Nov 8	0.9	99	2	No	0.424	0.102	1119
Nov 15	0.9	99	2	No	0.416	0.0993	1091
Nov 22	0.9	99	2	No	0.411	0.0969	1065
Nov 29	0.9	99	2	No	0.431	0.102	1117
Dec 6	0.9	99	2	No	0.426	0.102	1117
Dec 13	0.9	99	2	No	0.409	0.0970	1066
Dec 20	0.9	99	2	No	0.412	0.0983	1081
Nov 1	0.95	99	2	No	0.196	0.0479	526
Nov 8	0.95	99	2	No	0.210	0.0507	557
Nov 15	0.95	99	2	No	0.202	0.0475	522
Nov 22	0.95	99	2	No	0.201	0.0482	530
Nov 29	0.95	99	2	No	0.213	0.0504	554
Dec 6	0.95	99	2	No	0.206	0.0488	537
Dec 13	0.95	99	2	No	0.212	0.0500	550
Dec 20	0.95	99	2	No	0.206	0.0503	553
Nov 1	0.98	99	2	No	0.0863	0.0210	231
Nov 8	0.98	99	2	No	0.0791	0.0193	212
Nov 15	0.98	99	2	No	0.0826	0.0200	219
Nov 22	0.98	99	2	No	0.0883	0.0205	225
Nov 29	0.98	99	2	No	0.0815	0.0194	213
Dec 6	0.98	99	2	No	0.0850	0.0202	222
Dec 13	0.98	99	2	No	0.0769	0.0186	204
Dec 20	0.98	99	2	No	0.0793	0.0192	211

Date of Application	Proportion of Gulls Removed by Hazing	Time to Significant Rainfall Event (d)	Number of Applications	Dead Mice Removed?	Mean Total Ingested Dose (mg ai/kg bw)	Proportion of Dead Gulls	Number of Dead Gulls (#/11,000 Gulls)
Sensitivity Analysis[a]							
Nov 29	0.9	30	1	No	0.0332	0.0198	217
Nov 29	0.9	30	2	Yes	0.330	0.0918	1009

[a] These results were included to emphasize the effects that alterations of inputs have on the model

APPENDIX B – MODELING RESULTS FOR WESTERN GULLS EXPOSED TO DIPHACINONE ON THE FARALLON ISLANDS

Date of Application	Proportion of Gulls Removed by Hazing	Time to Significant Rainfall Event (d)	Number of Applications	Dead Mice Removed?	Mean Total Ingested Dose (mg ai/kg bw)	Proportion of Dead Gulls	Number of Dead Gulls (#/11,000 Gulls)
Nov 1	0.75	96	3	No	31.1	0.250	2750
Nov 8	0.75	96	3	No	31.9	0.251	2765
Nov 15	0.75	96	3	No	32.5	0.253	2781
Nov 22	0.75	96	3	No	31.8	0.247	2713
Nov 29	0.75	96	3	No	31.7	0.248	2731
Dec 6	0.75	96	3	No	31.4	0.246	2708
Dec 13	0.75	96	3	No	31.4	0.249	2742
Dec 20	0.75	96	3	No	30.8	0.246	2709
Nov 1	0.9	96	3	No	12.3	0.0996	1095
Nov 8	0.9	96	3	No	12.8	0.101	1108
Nov 15	0.9	96	3	No	12.7	0.0989	1088
Nov 22	0.9	96	3	No	12.2	0.0953	1047
Nov 29	0.9	96	3	No	12.7	0.0982	1080
Dec 6	0.9	96	3	No	13.0	0.101	1115
Dec 13	0.9	96	3	No	12.5	0.0991	1090
Dec 20	0.9	96	3	No	12.6	0.0997	1096
Nov 1	0.95	96	3	No	5.97	0.0484	532
Nov 8	0.95	96	3	No	6.15	0.0485	533
Nov 15	0.95	96	3	No	6.29	0.0489	537
Nov 22	0.95	96	3	No	6.34	0.0500	550
Nov 29	0.95	96	3	No	6.35	0.0499	548

Date of Application	Proportion of Gulls Removed by Hazing	Time to Significant Rainfall Event (d)	Number of Applications	Dead Mice Removed?	Mean Total Ingested Dose (mg ai/kg bw)	Proportion of Dead Gulls	Number of Dead Gulls (#/11,000 Gulls)
Dec 6	0.95	96	3	No	6.36	0.0500	550
Dec 13	0.95	96	3	No	6.49	0.0510	561
Dec 20	0.95	96	3	No	6.36	0.0505	555
Nov 1	0.98	96	3	No	2.54	0.0201	220
Nov 8	0.98	96	3	No	2.65	0.0205	225
Nov 15	0.98	96	3	No	2.36	0.0183	201
Nov 22	0.98	96	3	No	2.51	0.0199	218
Nov 29	0.98	96	3	No	2.50	0.0198	217
Dec 6	0.98	96	3	No	2.51	0.0194	213
Dec 13	0.98	96	3	No	2.68	0.0207	227
Dec 20	0.98	96	3	No	2.31	0.0185	203
Sensitivity Analysis[a]							
Nov 29	0.75	96	1	No	0.0691	0.0205	225
Nov 29	0.75	96	2	No	3.20	0.100	1098
Nov 29	0.75	96	3	Yes	12.8	0.100	1100

[a] These results were included to emphasize the effects that alterations of inputs have on the model

APPENDIX C – SENSITIVITY ANALYSIS FOR BRODIFACOUM MODEL

Varied Parameter	Value	Units	Mean Total Ingested Dose (mg ai/kg bw)	Proportion Dead Gulls	Number of Dead Gulls (#/11,000 Gulls)
Application Date	Nov 1		0.234	0.0718	790
	Nov 8		0.285	0.0844	928
	Nov 15		0.316	0.0899	988
	Nov 22		0.331	0.0922	1014
	Nov 29		0.343	0.0947	1042
	Dec 6		0.341	0.0933	1025
	Dec 13		0.336	0.0928	1020
	Dec 20		0.348	0.0947	1041
Applications Interval	5	days	0.320	0.0887	975
	12	days	0.343	0.0947	1042
	21	days	0.340	0.0932	1024
Number of Applications	1		0.0332	0.0198	217
	2		0.343	0.0947	1042
Hazing Effectiveness	0.75		0.861	0.236	2594
	0.9		0.343	0.0947	1042
	0.95		0.167	0.0459	504
	0.98		0.0690	0.0189	207
Pellet Half-life	0.5	days	0.364	0.0952	1046
	1	days	0.343	0.0947	1042
	2	days	0.342	0.0934	1027
Time to Significant Rainfall Event After 2nd Application	14	days	0.267	0.0818	900
	30	days	0.343	0.0947	1042
	99	days	0.431	0.102	1117
Mean (SD) Concentration in Mice	2.71 (0.7)	mg/kg ww	0.333	0.0920	1012
	4.9 (1.26)	mg/kg ww	0.343	0.0947	1042
Daily Probability of Consuming Mice Prior to Brodifacoum Application	0.01		0.333	0.0914	1005
	0.125		0.343	0.0947	1042
	0.15		0.334	0.0923	1015
Daily Probability of Consuming Pellets Following Brodifacoum	0.22		0.316	0.0901	991
	0.25		0.343	0.0947	1042

Varied Parameter	Value	Units	Mean Total Ingested Dose (mg ai/kg bw)	Proportion Dead Gulls	Number of Dead Gulls (#/11,000 Gulls)
Application					
Conditional Probability for Consuming Mice	0.5		0.337	0.0926	1018
	0.7		0.342	0.0945	1039
	0.9		0.343	0.0947	1042
Conditional Probability for Consuming Pellets	0.5		0.305	0.0956	1051
	0.7		0.309	0.0947	1041
	0.9		0.343	0.0947	1042
Proportion of Mouse Population Below Ground Following Onset of Symptoms	0.87		0.343	0.0947	1042
	0.935		0.343	0.0954	1049
	1		0.339	0.0946	1040
LD50	0.26	mg/kg bw	0.343	0.0947	1042
	0.424	mg/kg bw	0.336	0.0916	1007
	0.588	mg/kg bw	0.332	0.0879	966

APPENDIX D – SENSITIVITY ANALYSIS FOR DIPHACINONE MODEL

Varied Parameter	Value	Units	Mean Total Ingested Dose (mg ai/kg bw)	Proportion Dead Gulls	Number of Dead Birds (#/11,000 birds)
Application Date	Nov 1		12.3	0.0996	1095
	Nov 8		12.8	0.101	1108
	Nov 15		12.7	0.0989	1088
	Nov 22		12.2	0.0953	1047
	Nov 29		12.7	0.0982	1080
	Dec 6		13.0	0.101	1115
	Dec 13		12.5	0.0991	1090
	Dec 20		12.6	0.0997	1096
Applications Interval	3	days	16.2	0.0985	1083
	7	days	12.7	0.0982	1080
	10	days	12.8	0.101	1114
Number of Applications	1		0.0691	0.0205	225
	2		3.20	0.0999	1098
	3		12.7	0.0982	1080
Hazing Effectiveness	0.75		31.7	0.248	2731
	0.9		12.7	0.0982	1080
	0.95		6.35	0.0499	548
	0.98		2.50	0.0198	217
Pellet Half-life	0.5	days	14.9	0.0984	1082
	1	days	12.7	0.0982	1080
	2	days	13.1	0.102	1126
Mean (SD) Concentration in Mice	30 (7.5)	mg/kg ww	13.0	0.101	1114
	51.5 (13)	mg/kg ww	12.7	0.0982	1080
Daily Probability of Consuming Mice Prior to Diphacinone Application	0.01		12.8	0.100	1101
	0.125		12.7	0.0982	1080
	0.15		12.4	0.0971	1068
Daily Probability of Consuming Pellets Following Diphacinone Application	0.22		12.0	0.0969	1066
	0.25		12.7	0.0982	1080
Conditional	0.5		12.7	0.0994	1093

Varied Parameter	Value	Units	Mean Total Ingested Dose (mg ai/kg bw)	Proportion Dead Gulls	Number of Dead Birds (#/11,000 birds)
Probability for Consuming Mice	0.7		13.3	0.103	1130
	0.9		12.7	0.0982	1080
Conditional Probability for Consuming Pellets	0.5		11.6	0.101	1115
	0.7		11.6	0.100	1103
	0.9		12.7	0.0982	1080
Proportion of Mouse Population Below Ground Following Onset of Symptoms	0		12.6	0.0982	1080
	0.87		12.7	0.0982	1080
	1		12.8	0.100	1103
LD50	0.82	mg/kg bw	12.7	0.0982	1080
	48.91	mg/kg bw	12.9	0.0987	1085
	97	mg/kg bw	12.7	0.0695	764