HONORABLE MICHELLE L. PETERSON

UNITED STATES DISTRICT COURT
WESTERN DISTRICT OF WASHINGTON
AT SEATTLE

WILD FISH CONSERVANCY NORTHWEST, a Washington non-profit corporation, Plaintiff, v. BARRY THOM, in his official capacity as Regional Administrator of the National Marine Fisheries Service, *et al*, Defendants.	Case No. 2:20-cv-00417-MLP **DECLARATION OF DR. ROBERT LACY, Ph.D.**

I, Robert Lacy, state and declare as follows;

1. I am over eighteen years of age. I have personal knowledge of the facts contained in this declaration and am otherwise competent to testify to the matters in this declaration.

2. I received my B.A. and M.A. in Biology from Wesleyan University in 1977, where I graduated summa cum laude. I received my Ph.D. in Evolutionary Biology with minors in Genetics and Ecology from Cornell University in 1982. I serve on the faculty of the Committee on Evolutionary Biology at University of Chicago. I was a Conservation Scientist for the Chicago Zoological Society from 1985, until my recent retirement and appointment as a Conservation Scientist Emeritus. Although “retired” I still work actively with the Species

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Conservation Toolkit Initiative, a team that develops, distributes, and supports software for species risk assessments and wildlife population management.

3. My qualifications, including publications, is contained in my Curriculum Vitae, which is attached as Exhibit B to this declaration.

4. I have been retained by Wild Fish Conservancy, through its counsel, to provide expert opinions in this matter on issues related to the Southern Resident Killer Whale population and the implications of the National Marine Fisheries Service's ("NMFS") conclusions in the Biological Opinion issued with regard to the 2019 Pacific Salmon Treaty. This declaration describes my opinions and the bases therefor.

5. In addition to drawing upon my knowledge and expertise, I have reviewed the materials cited throughout this declaration and those identified in the list of cited materials attached to this declaration as Exhibit A in developing my opinions expressed herein.

6. In summary, the opinions I express herein are as follows:

a. Analyses conducted in 2015 projected that the Southern Resident Killer Whale population would decline slowly at a rate of about 0.2% per year if environmental conditions and the demographic responses to threats remained as they had been over the previous few decades. Updated analyses on the current population now project about a 1% annual decline, leading to eventual extinction of the population as demographic and genetic problems become worse with the ongoing decline in the breeding population. The numbers of Southern Resident Killer Whales increased from 1976 to a peak in 1993-1996, and has subsequently declined. The 2015 prediction of approximately zero population growth accurately reflected the lack of growth in numbers over the entire time period

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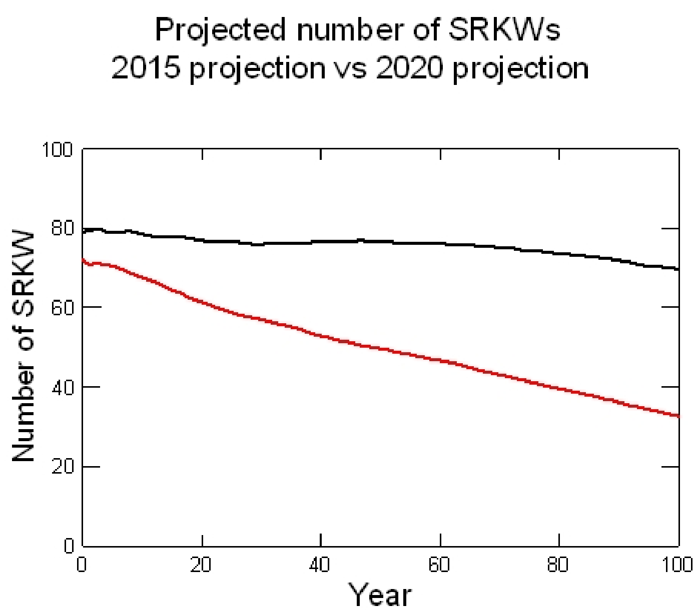
from 1976 to 2020, while the more pessimistic current prediction accurately mirrors the 1% average annual decline that has occurred since 1993. Since 2014, the Southern Resident Killer Whale population has declined at an even faster rate of about 2% per year. Although the difference between a 0.2% annual decline and a 1% annual decline might not seem large, the cumulative effect of the faster rate of decline compounds to become considerable damage across the years. The following graph shows the mean projected number of Southern Resident Killer Whales, using the data from 2015 (upper, black line) and the mean projected number using the current (2020) data (lower, red line). In 2015, we estimated a 9% probability that the population would become functionally extinct with fewer than 30 animals within the next 100 years. With updates to reflect the current situation, I now estimate a 59% probability that the population will drop below 30 animals sometime in the next 100 years, becoming functionally extinct.



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b. The abundance of Chinook prey influences the reproductive rate and the survival rates of the Southern Resident Killer Whale. Analyses indicate that prey abundance is the factor that has the largest impact on Southern Resident Killer Whale population growth or decline. Using published estimates of the effect of prey abundance on demographic rates, we calculate that Chinook total abundance available as prey to the Southern Resident Killer Whale needs to increase by about 10% over the mean levels of the last few decades for the decline of the Southern Resident Killer Whale to be halted. Recovery of the Southern Resident Killer Whale population at the rate (2.3% growth) specified for delisting in the species' Recovery Plan will require an increase in the Chinook prey abundance of about 35%.

c. The NMFS 2019 Biological Opinion ("2019 SEAK BiOp") proposes several actions aimed at increasing the number of Chinook salmon available to the Southern Resident Killer Whales. The reduction in the Southeast Alaska salmon fishery of up to 7.5% in the 2019 Pacific Salmon Treaty relative to the preceding agreement, which is described in the 2019 SEAK BiOp, results in very little change in the Chinook available to the Southern Resident Killer Whales, and therefore would not have a measurable benefit for the endangered Southern Resident Killer Whale.

d. A proposed hatchery expansion aims to increase Chinook available to the Southern Resident Killer Whales by 4-5%. That increase in prey can be estimated to reduce the annual rate of decline of the Southern Resident Killer Whale population from about 1% to about 0.5%, but this would not be sufficient to stop

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the slide toward extinction.

e. The benefits to the Southern Resident Killer Whales of other possible mitigation measures are not quantified in the 2019 SEAK BiOp, and those actions would need to amount to a further increase (above that achieved from the two above mentioned measures) of at least another 5% in the Chinook abundance available as prey to Southern Resident Killer Whales in order for me to predict that the decline of Southern Resident Killer Whales would stop.

f. More aggressive management actions would be required to start the Southern Resident Killer Whale population on a reasonably secure path toward recovery or to meet NMFS' annual population growth rate goal of 2.3%.

7. My career has focused on building the capacity of the world to be much more effective in ensuring the long-term sustainability of species. I have done this via advancing the basic science that must underlie successful programs for sustaining species; providing the accessible tools to enable others to apply the science to species assessments, conservation planning, and population management; training students and colleagues in the use of the tools; and – when necessary – doing the analyses that inform and guide conservation for individual species.

8. Over my career I have developed, freely distributed, and supported software tools for guiding species conservation and population management. My approach has always been to provide tools for powerful and flexible analyses, within user interfaces that are accessible to wildlife managers, students, and others who might not have expertise with computer languages and systems. Consequently, the tools are now used globally to guide population management in nature reserves and zoos, viability analyses and recovery planning by wildlife agencies, and

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integrated assessment of threats to species. The software is used also to teach students about population biology and conservation in many universities.

Population Viability Analysis

9. Population viability analysis (PVA) is a class of scientific techniques that uses demographic modeling to assess risks to wildlife populations and evaluate the likely efficacy of protection, recovery, or restoration options (Shaffer 1990; Boyce 1992; Burgman et al. 1993; Sjögren-Gulve and Ebenhard 2000; Beissinger and McCullough 2002; Morris and Doak 2002). (All references cited in this Declaration are listed in Exhibit A.) PVA usually starts with standard demographic analysis ("life table analysis") to make deterministic projections of the expected population growth rate from the mean birth and death rates (Ricklefs 1990; Caswell 2001). PVA then extends the standard demographic projections in two important ways: (1) the impacts of forces external to the population (e.g., changing habitat quality, extent, and configuration; interactions with other species in the community; impacts of disease or contaminants; harvest, incidental killing, or other direct human impacts) on the demographic rates are explicitly considered and evaluated, and (2) uncertainty in the population trajectory caused by intrinsic (e.g., demographic stochasticity, limitations in local mate availability or other density dependent feedbacks, inbreeding impacts) and extrinsic (e.g., environmental variation, occasional catastrophes) factors can be explicitly modeled, usually through the use of simulation modeling. The outputs of PVA include any desired measure of population performance, but commonly assessed metrics include projected mean population size (N) over time, population growth rates (r), expected annual fluctuations in both N and r, probability of population extinction, and probabilities of quasi-extinction (the likelihood of N falling below any specified number within a specific number of years). These outputs are used to assess risk (e.g., for listing under the

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Endangered Species Act or other protective regulations), assess vulnerability to possible threats, determine sustainable harvest in the context of uncertainty, and determine the suites of actions that would be needed to achieve stated resource protection or restoration goals.

10. A requirement for any PVA model to provide sufficiently accurate and robust projections to allow estimation of population performance is the availability of detailed demographic data. Model input is required from the focal population or comparable reference populations for mortality rates, aspects of reproduction (e.g., age of breeding, age of reproductive senescence, inter-birth intervals, and infant survival), population size, and habitat carrying capacity – as well as the natural fluctuations in these rates. The difficulty in obtaining sufficient demographic data on endangered or protected species is a common challenge to the usefulness of PVA models, and many practitioners consequently recommend that PVA models be used only to provide assessments of relative risk and relative value of management options, rather than absolute measures of population trajectories. In the case of the Southern Resident Killer Whale population, however, demographic data are available from studies by the Center for Whale Research and others that are unprecedented in duration and detail of data collection. This exceptional data set provides a complete census of the total abundance as well as the age and sex composition of the Southern Resident Killer Whale population from 1976 to 2020. This allows for much more accurate projections of population performance and the ability to compare predicted trajectories to the precisely documented fate of the population.

11. PVA models were developed initially for quantifying future risk to populations that are vulnerable to collapse due to a combination of threatening processes (Shaffer 1990). They were soon recognized to be more reliable for assessing relative risk than absolute probabilities of decline or extinction (Beissinger and McCullough 2002; but see Brook et al.

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2000 for evidence that even absolute predictions of population trends can be accurate), and have become most useful in the identification of conservation actions that are most likely to achieve conservation goals (Sjögren-Gulve and Ebenhard 2000). The same methods can be used to quantify injury caused by an externally imposed stress, by comparing measures of population performance in the presence vs. absence of the stress, and to determine what actions would be needed to reverse the impact, restore the population to pre-injury health, and compensate for interim losses. The PVA forecasts can then be used to set the targets for expected performance under proposed restoration plans.

12. The Vortex PVA model that I developed (Lacy and Pollak 2020) is what is known as an individual-based model that projects the fate of each individual in a population. It simulates the effects of both deterministic forces and demographic, environmental and genetic stochastic (or random) events on wildlife populations. Vortex models population dynamics as sequential events that are determined for each individual in a population with probabilities determined from user-specified distributions. Vortex simulates a population by stepping through a series of events that describe an annual cycle of a sexually reproducing organism: mate selection, reproduction, mortality, dispersal, incrementing of age by one year, any managed removals from, or supplementation to, the populations, and limitation of the total population size (habitat "carrying capacity"). The simulations are iterated to generate the distribution of fates that the population might experience. Vortex tracks the sex, age, and parentage of each individual in the population as demographic events (birth, sex determination, mating, dispersal, and death) are simulated. A detailed description of the program structure is provided in Lacy (1993; 2000) and details about the use of Vortex are provided in the manual (Lacy et al. 2020).

13. The Vortex PVA modeling software is well-suited for the analyses of threats to

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the Southern Resident Killer Whale population, as Vortex is the most widely used, tested, and validated individual-based PVA model, and it is publicly accessible so that anyone can re-examine and repeat published analyses. It is highly flexible in allowing all input demographic parameters to be specified optionally as functions of external forces or as rates that change over time. Vortex has been used for modeling population dynamics of various marine mammal species (including bottlenose dolphins, Indo-Pacific bottlenose dolphins, baiji, manatees, dugongs, Hawaiian monk seals, and Mediterranean monk seals), as well as thousands of other species. Vortex has been shown to produce projections that accurately forecast dynamics of well-studied populations (Brook et al. 2000). Both NMFS in its 2019 SEAK BiOp (e.g., pp. 86, 90, 311) and Fisheries and Oceans Canada (Murray et al. 2019, e.g., pp. 3-5, 30, 33, 44, 62) have relied on analyses completed with Vortex for assessing the status of the Southern Resident Killer Whales.

<u>Southern Resident Killer Whales</u>

14. In 2015, at the request of Canada's National Energy Board ("NEB"), I led a team of six scientists conducting a PVA of the risk associated with aspects of the proposed Trans Mountain Expansion Project (Project) on the endangered Southern Resident Killer Whales. In that analysis, the PVA model was used to estimate the increased risk to the Southern Resident Killer Whales from three threats associated with the marine shipping component of the Project: an oil spill, increased acoustic and physical disturbance from ships, and ship strikes. The report also examined the possible effects of decreased Chinook salmon prey base that might result from climate change or human activities, and evaluated those impacts in comparison to the more immediate threats of the proposed Project and as the environmental context within which the impacts of the Project are likely to occur. The report to NEB (Lacy et al. 2015), including

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detailed descriptions of the methods and the data used in the PVA, is publicly available at http://docs.neb-one.gc.ca/fetch.asp?language=E&ID=A4L9G2. The analyses were extended and published in a peer-reviewed scientific paper (Lacy et al. 2017). Further updating of analyses using demographic data on the population through 2018 (Lacy et al. 2018) was submitted to NEB and is available at https://apps.cer-rec.gc.ca/REGDOCS/Search?txthl=A96429-3%20A%20-%20Expert%20Report%20of%20Lacy%20et%20al%20-%202018%20-%20Final%20-%20A6L5R2.

15. As of 2015 and 2017, based on status quo conditions, we projected the Southern Resident Killer Whale population would remain about at its current size or continue a very slow decline (estimated at a mean annual decline of 0.2%). We projected a 9% chance of quasi-extinction within the next 100 years, where the population falls below 30 whales and is no longer viable.

16. I have now updated the PVA model again, using fecundity and survival rates calculated from the detailed records from 1976 through 2018 and applying those rates to the current population of 72 Southern Resident Killer Whales. The following graph shows the mean projected population size (heavier, middle line) and the uncertainty in the trajectory (upper and lower lines showing ± 1 standard deviation among independent repeated simulations of the population).

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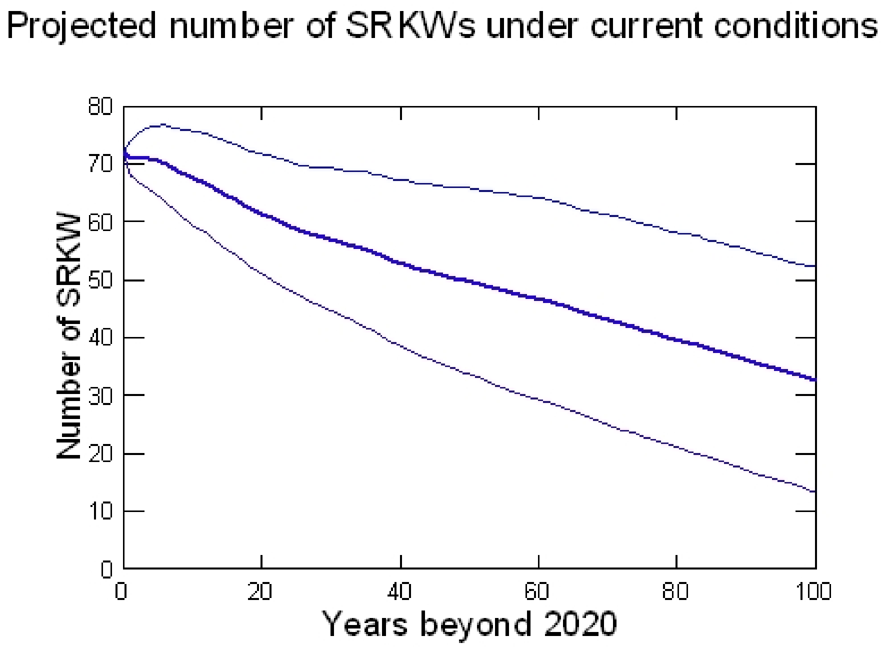

17. With current data, and if the Chinook availability remains at the mean level of the past few decades, the model projects a mean annual decline in the population of Southern Resident Killer Whales of about 1.0%. This is close to what has been occurring recently, and it compares to our 2018 projection of a smaller decline of 0.6% per year (Lacy et al. 2018). About half of difference between the 2018 and 2020 projections is due to the fact that the population is aging (with the mean age of living whales now just over 22 years, whereas it was just over 21 years in 2018), and more animals are now post-reproductive or nearing post-reproductive age. The other half of the difference is due to the fact that we now have parentage data for more of the animals, and that allows us to have more complete estimates of kinships among animals, and that in turn leads to slightly higher estimates of current and future inbreeding.

18. For our model, we obtained estimates of the impact of Chinook prey abundance on the reproductive rates and survival rates of the Southern Resident Killer Whales from published scientific reports (Ward et al. 2009; Velez-Espino et al. 2015; Ford et al. 2010). We

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scaled the numerical relationships so that the mean demographic rates observed in the Southern Resident Killer Whales from 1976 through 2015 were correctly predicted. (The details of the methodology are documented in Lacy et al. 2015 and Lacy et al. 2017 publications.) We then use these relationships to project the Southern Resident Killer Whale population trajectory in several scenarios that tested the impact of prey availability, expressed as a percent change in the annual abundance of Chinook salmon available as prey to the Southern Resident Killer Whales from the mean level over the last three decades.

19. The abundance of Chinook varies over time, and that variation in prey can be entered into the PVA model. However, as documented in the 2019 SEAK BiOp, the extent of that variation is very dependent on which stocks of Chinook are assessed, and it is not known precisely what proportion of the Southern Resident Killer Whale diet is composed of salmon from each stock. I examined the model projections with the Chinook abundance varying randomly across years around the long-term mean values being tested. I found that such an elaboration of the model had very little effect on the long-term projections for the Southern Resident Killer Whale population. This occurs because killer whales are very long-lived and slow breeders, so year to year fluctuations in demography will average out over their lifespans. Therefore, as was done in our prior PVA reports, the results from analyses presented in this declaration assume that the abundance of Chinook is at a fixed level each year and does not vary randomly around that value.

20. Also included in the model are the current estimates of both PCBs and noise disturbance, based on published estimates of the current magnitudes and effects of these threats (Hall et al. 2011; Hall and Williams 2015; Lusseau et al. 2009). These threats are part of the current environment for the Southern Resident Killer Whale, and they interact with the effect of

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prey limitation. (The documented impact of noise disturbance is via a reduction in time that the Southern Resident Killer Whales spend feeding. The primary impact of PCBs is on survival of calves, compounding the reduction in survival that occurs with low prey availability.) Only with these effects of PCB and noise disturbance in the model do we accurately predict the recent observed rate of decline of the population. However, even if these other threats were completely eliminated—which is not possible in the near term and unlikely in the long term—our modeling shows that there would not be adequate prey available to achieve the population growth goal established in the Recovery Plan for the Southern Resident Killer Whale (Lacy et al. 2017).

21. By applying the published relationships of Southern Resident Killer Whale reproductive and survival rates to Chinook abundance, and then testing the benefits to Southern Resident Killer Whales of incremental improvements in the abundance of Chinook prey, the model shows that to achieve a mean zero population growth (i.e., to stop the decline), there would need to be a sustained 10% increase (relative to the 1976-2015 average) in the mean abundance of the Chinook stocks available as prey to the Southern Resident Killer Whales.

22. The analyses conducted in 2015, 2017, and 2018 estimated that a 30% increase in Chinook could achieve the 2.3% growth called for in the Southern Resident Killer Whale Recovery Plan. With the further decline that has occurred in the population in the last few years, our analysis of the 2020 population now projects that a 30% increase in Chinook would result in about 2% growth per year, and a 35% increase in prey would be necessary to meet the recovery goal. The graph below shows the expected Southern Resident Killer Whale population growth across a range of levels of Chinook abundance. The two horizontal lines indicate zero population growth and the 2.3% growth goal of the Recovery Plan.

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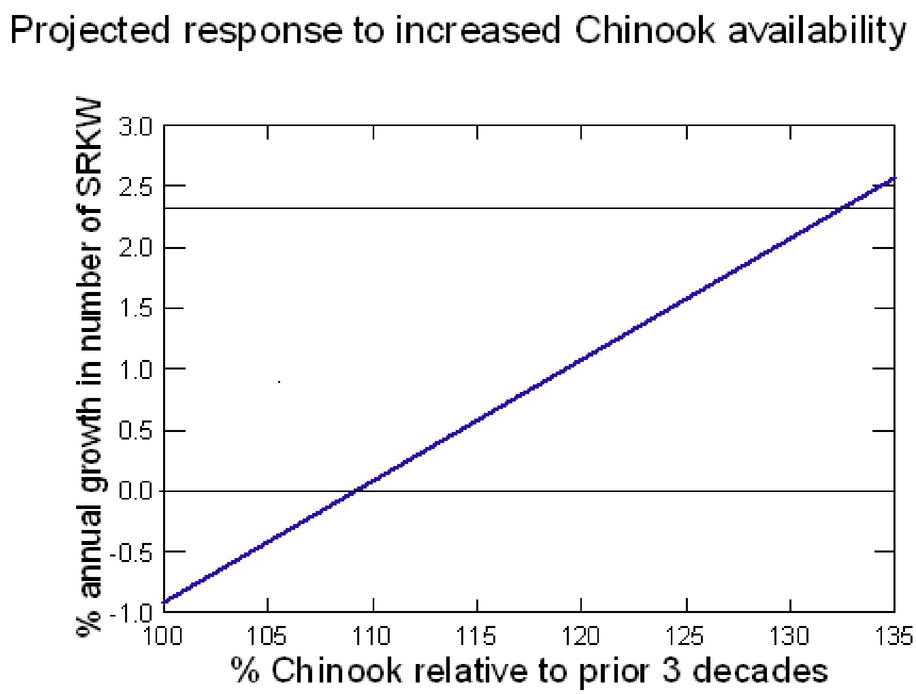

<u>NMFS' Biological Opinion and Impact on Southern Resident Killer Whale Population</u>

23. I was provided with NMFS' 2019 SEAK BiOp for Southeast Alaska salmon fisheries at issue in this matter. I reviewed it closely. In the 2019 SEAK BiOp, NMFS acknowledges that the Southern Resident Killer Whale population is declining, and that is at least partly and maybe mostly due to inadequate prey availability. The 2019 SEAK BiOp cites my previous work (p. 311) as evidence that the biggest threat is that lack of prey, although other factors such as noise, PCBs, oil spills, and other environmental factors all make things worse.

24. In several places, and in various ways, the 2019 SEAK BiOp estimates the reduction in prey available for Southern Resident Killer Whales caused by the Southeast Alaska fisheries (e.g., Tables 41, 42, and 97) as between 2-15% in coastal fisheries and 1-2% in inland fisheries. However, there is significant uncertainty depending on which salmon stocks and for which years the calculations are based. Importantly, the BiOp does not explain how the various percentage reductions mentioned translate to corresponding changes in the total mean abundance of Chinook that provide potential prey for Southern Resident Killer Whales, which is what is

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required for accurate projections of the benefits expected from reductions in the fisheries. The 2019 SEAK BiOp directly states (p. 94) "the impact of reduced Chinook salmon harvest on future availability of Chinook salmon to the Southern Residents is not clear."

25. The 2019 SEAK BiOp also discusses possible mitigation measures, which could increase the prey availability for Southern Resident Killer Whales. The 2019 SEAK BiOp estimates the newly negotiated 2019 Pacific Salmon Treaty will reduce the Southeast Alaska fishery annual harvest of Chinook by up to 7.5% relative to the harvest under the 2009 Treaty. A proposed increase in hatchery production mitigation seeks to provide 4 to 5% increase in prey available to the Southern Resident Killer Whales. The increase in hatchery production is not yet funded, so I would expect a delay of at least 5 to 10 years to account for allocation of funds, construction of any new facilities, increased programs of production, and then return of hatchery raised Chinook as mature adults.

26. I applied these estimates from the 2019 SEAK BiOp to the Vortex PVA model, in order to project the consequences of the possible scenarios described in the 2019 SEAK BiOp. The estimated 7.5% (maximum) reduction in the Southeast Alaska fishery, applied to a typical 6% reduction in prey available to the Southern Resident Killer Whales caused by the Southeast Alaska fishery as a whole (the 6% being an approximate middle value from the many estimates made in the BiOp), results in a less than 0.5% increase in the Southern Resident Killer Whale prey. This is only 1/20th of the 10% increase that is needed to achieve even a cessation of the decline in Southern Resident Killer Whale population.

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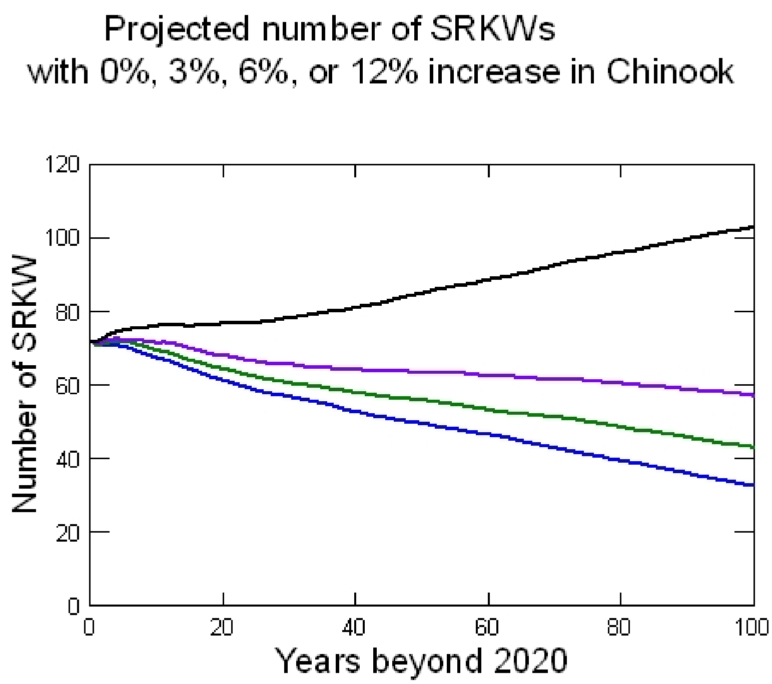
27. To estimate the possible reductions in threats to the Southern Resident Killer Whale that might be achieved with greater reductions in the Chinook fisheries, I projected a Southern Resident Killer Whale population growth with an immediate 6% increase in Chinook prey, and a 3% and a 12% increase in prey (half and double the middle estimate, covering most of the range of values reported in the 2019 SEAK BiOp for specific stocks and years). As shown in the following graph, with the existing baseline in blue (bottom line), the PVA projections for these scenarios show that the 3% increase in Chinook results in a mean 0.7% decline in Southern Resident Killer Whale population per year (green line), the 6% increase in Chinook results in a mean 0.4% decline of the Southern Resident Killer Whale population (purple line), and the 12% increase results in 0.3% positive growth annually (top, black line).



28. The impacts on Southern Resident Killer Whales of other estimates of prey increases that could be achieved by reductions in the fisheries can be extrapolated from the projections of Southern Resident Killer Whale population growth across a range of levels of Chinook abundance, as shown in the graph in paragraph 22, above.

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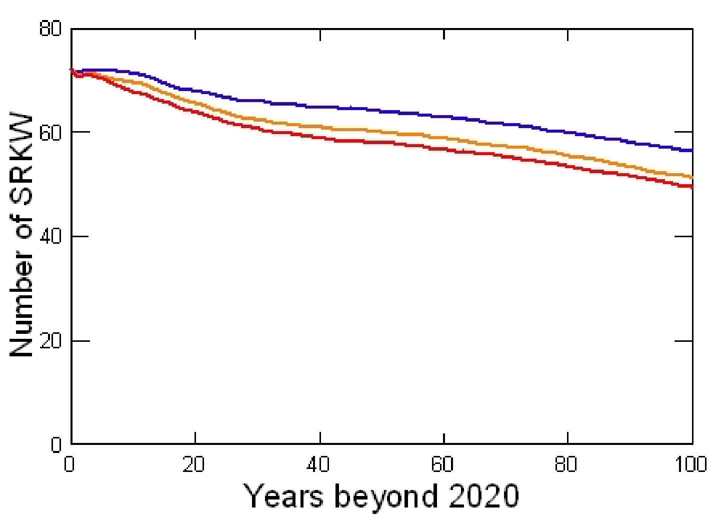
29. I projected the benefits to the Southern Residents of possible (but not yet funded) hatchery projects assuming a 5% increase in Chinook, beginning either 5 years or 10 years in the future. With either time scale for implementation and return of the hatchery-produced Chinook, the mean long-term consequence is a slowing of the decline in Southern Resident Killer Whales from 1.0% to 0.5% per year; therefore, not enough improvement to completely halt the decline. The difference between a 5-year delay and a 10-year delay in enhancement is that by year 10, the slower implementation will result in the Southern Resident Killer Whale population having declined by about 2 more whales before the improvement can begin to take effect. The following graph shows the projections if the mitigation measures achieve a 5% increase in Chinook (as estimated from the proposed hatchery expansion) instantly (top, blue line), after 5 years (middle, orange line), or after 10 years (bottom, red line). As this graph plainly demonstrates, delays in implementation of these theoretical mitigation measures have a very real and lasting impact on the Southern Resident population. Notably, it also shows that the proposed measure – even if implemented immediately – is not enough to stop the decline of Southern Residents.

Projected number of SRKWs with 5% increase in Chinook, implemented over 0, 5, or 10 years



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30. Combining the actions of reducing the Southeast Alaska Chinook fishery and increasing abundance to the Southern Resident Killer Whale of hatchery-raised Chinook, and possibly other mitigating actions as well (such as additional reductions in additional fisheries managed under the Pacific Salmon Treaty), could achieve the 10% increase in prey necessary for stabilization of the Southern Resident Killer Whale population or even greater increases in prey that would allow for recovery of the Southern Resident Killer Whales. Importantly, however, none of the scenarios proposed in the 2019 SEAK BiOp are projected to achieve this 10% increase in prey abundance. The analyses described above in paragraph 22 document the long-term growth in the Southern Resident Killer Whale population that could be achieved if Chinook abundance is increased by 35% above the mean levels of the last three decades.

31. Implementing mitigation measures, however, will likely require time. To examine responses of the Southern Resident Killer Whale population to delayed implementation, I tested models with increases in the prey abundance starting either 5 years or 10 years from now. The following graph shows the mean projected Southern Resident Killer Whale population size when a 10% increase in Chinook is implemented immediately (top, blue line), after 5 years (middle, orange line), or after 10 years (bottom, red line). The long-term population growth rates after implementation again show that a 10% increase in prey is needed to stop the decline of Southern Resident Killer Whales. However, before that positive result is achieved, the population will have lost 4 whales if implementation takes 5 years, or 8 whales if implementation takes 10 years, relative to the expected population size if the increase in prey were achieved immediately. With positive growth of Southern Resident Killer Whale numbers after implementation of sufficient mitigation measures, a delay in implementation results in a loss of the potential initial years of recovery, and that lack of growth for those initial years leaves the population at a deficit in

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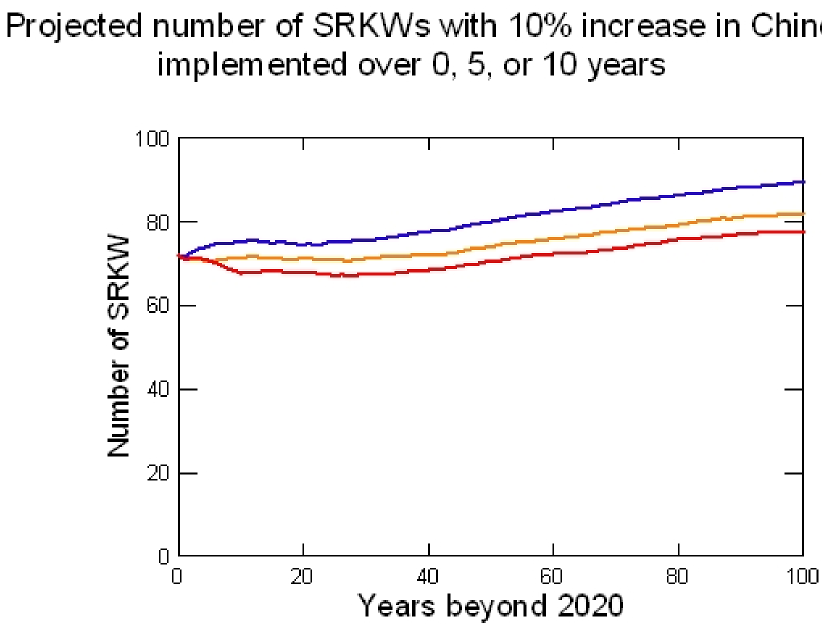
numbers throughout the subsequent recovery compared to what could have been. A 20% increase in Chinook allows for a long-term population growth of about 1% annually, but a delay of 5 or 10 years results in a loss of 8 or 16 whales before the growth begins, respectively, relative to the expected population size if growth had started in 2020.



32. In summary, although the 2019 SEAK BiOp does not provide management targets for slowing, stopping, or reversing the decline of the Southern Resident Killer Whale population, and it does not give specific estimates of the benefits to the Southern Resident Killer Whales of the proposed mitigation measures, for the above analyses I extracted from the 2019 SEAK BiOp what I could regarding the expected benefits of proposed actions. The 2019 SEAK BiOp provides various estimates of changes to Chinook stocks that might be expected from two of the mitigation measures – a reduction in the Southeast Alaska Chinook fishery as specified in the 2019 Pacific Salmon Treaty, and a proposed hatchery expansion – and it mentions other possible actions, such as habitat improvements, for which there is no quantification of expected results. Only if the additional, as yet unquantified, mitigation measures can boost Chinook abundance by

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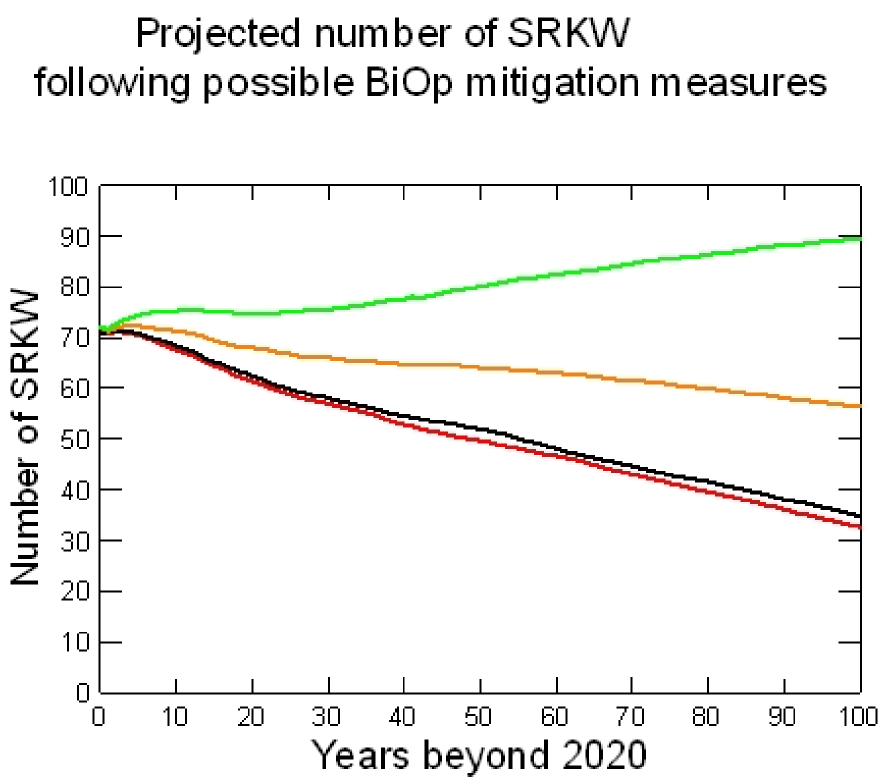
another 5%, would the combined effect of the proposed actions yield the 10% increase in Chinook that is necessary to halt the decline of the Southern Resident Killer Whales. The following graph summarizes the expected trajectory of the Southern Resident Killer Whale population if no changes are made from current conditions (bottom, red line), if a 0.5% increase in overall Chinook available to Southern Resident Killer Whales is produced by the reduced Chinook harvest in the 2019 Pacific Salmon Treaty (black line), if a 5% increase in Chinook is achieved by the hatchery mitigation (orange line), or if sufficient actions can be taken to achieve a 10% increase in Chinook (top, green line).



Conclusions

33. Based on previously published analyses, the results of updated models, my professional experience, and the information contained in the 2019 SEAK BiOp, I make the following conclusions with a reasonable degree of certainty:

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a. The Southern Resident Killer Whale population is in decline, and the projected status has deteriorated in just the past few years. The PVA models, using the latest available data on the current numbers, reproduction, and survival, project accurately the recent population changes.

b. The abundance of Chinook salmon prey available to the Southern Resident Killer Whales is a critical determinant of Southern Resident Killer Whale reproductive success and survival.

c. The mean Chinook abundance over recent years is not enough to allow reproduction by the Southern Resident Killer Whales sufficient to offset mortalities. An increase of about 10% in Chinook abundance would be required to stop the decline of Southern Resident Killer Whales, and an increase of about 35% in Chinook abundance would be required to achieve the healthy population growth rate of 2.3% that is the stated goal in the Southern Resident Killer Whale Recovery Plan.

d. The proposed mitigation measures in the 2019 SEAK BiOp have not been shown to be adequate to protect the future of the Southern Resident Killer Whale population – a short-coming that is admitted even within the 2019 SEAK BiOp. The quantitative estimates made in the 2019 SEAK BiOp would account for, at best and after full implementation, a reduction of half in the rate of decline in numbers of Southern Resident Killer Whales.

e. Full closure of the Southeast Alaska Chinook fishery, especially if combined with other mitigation measures, could result in enough prey to sustain a growing population of Southern Resident Killer Whales. Further enhancement measures

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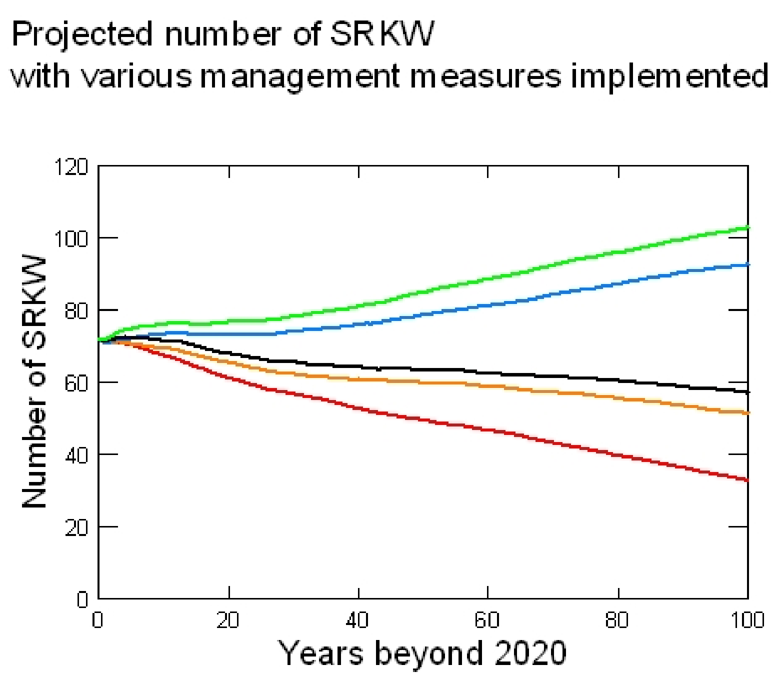
would be required to achieve the recovery goals set in the Recovery Plan for the Southern Resident Killer Whale. The last graph, below, shows projected Southern Resident Killer Whale numbers under current environmental conditions and management (bottom, red line), with the 5% increase in Chinook prey after 5 years, projected to result from the proposed hatchery enhancements (orange line), with a 6% increase in Chinook prey as might be achieved if the Southeast Alaska Chinook fishery is immediately closed (black line), with both the proposed hatchery project plus an additional 6% increase in Chinook abundance (blue line), or if a 12% increase in prey is achieved by the closure of the Southeast Alaska Chinook fishery (top, green line). The amount of increase in Chinook abundance as a result of reductions or closure of fishery harvests and other measures is uncertain, so responses of both the Chinook abundance and then the Southern Resident Killer Whale demography should be monitored closely, with adaptive management adjusting mitigation and enhancement measures as needed.



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I declare under penalty of perjury under the laws of the United States of America that the foregoing is true and accurate.

Executed this 15th day of April, 2020.

Robert Lacy, Ph.D.

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EXHIBIT A

Exhibit A – Publications cited

Beissinger, S.R., and D.R. McCullough (eds.). 2002. Population Viability Analysis. Chicago University Press, Chicago. 577 pp.

Boyce, M.S. 1992. Population viability analysis. Annual Review of Ecology and Systematics 23:481-506.

Brook, B.W., J.J. O'Grady, A.P. Chapman, M.A. Burgman, H.R. Akcakaya, and R. Frankham. 2000. Predictive accuracy of population viability analysis in conservation biology. Nature 404:385-387.

Burgman, M., S. Ferson and H.R. Akçakaya. 1993. Risk Assessment in Conservation Biology. Chapman and Hall, New York.

Caswell, H. 2001. Matrix Population Models. 2nd ed. Sinauer, Sunderland, Mass. 722 pp.

Ford, J.K.B., G.M. Ellis, P.F. Olesiuk, and K.C. Balcomb. 2010. Linking killer whale survival and prey abundance: food limitation in the oceans' apex predator? Biology Letters 6:139-142.

Hall, A.J., L. Schwacke, B.J. McConnell, and T.K. Rowles. 2011. Assessing the population consequences of pollutant exposure to cetaceans using an individual based modelling framework. Paper SC/63/E5, International Whaling Commission, Tromsø, Norway.

Hall, A.J. and R. Williams. 2015. The potential effect of PCBs on Killer whales – using the 'SPOC' individual based pollution model approach to estimate impacts on population growth. International Whaling Commission Scientific Committee meeting document SC/66a/E/2.

Lacy, R.C. 1993. VORTEX: A computer simulation model for Population Viability Analysis. Wildlife Research 20:45-65.

Lacy, R.C. 2000. Structure of the VORTEX simulation model for population viability analysis. Ecological Bulletins 48:191-203.

Lacy, R.C., K.C. Balcomb III, L.J.N. Brent, D.P. Croft, C.W. Clark, and P.C. Paquet. 2015. Report on Population Viability Analysis model investigations of threats to the Southern Resident Killer Whale population from Trans Mountain Expansion Project. Attachment E, Ecojustice – Written

Evidence of Raincoast Conservation Foundation (A70286), National Energy Board (Canada). 120 pp. Available at http://docs.neb-one.gc.ca/fetch.asp?language=E&ID=A4L9G2.

Lacy, R. C., R. Williams, E. Ashe, Kenneth C. Balcomb III, L. J. N. Brent, C. W. Clark, D. P. Croft, D. A. Giles, M. MacDuffee, and P. C. Paquet. 2017. Evaluating anthropogenic threats to endangered killer whales to inform effective recovery plans. Scientific Reports 7(1):1-12.

Lacy, R., P. Paquet, and M. MacDuffee. 2018. Population Viability Analyses for the Southern Resident Killer Whales. ATTACHMENT A To the Evidence of Raincoast Conservation Foundation (A96429-3 A - Expert Report of Lacy at al – 2018 – Final – A6L5R2). Available at: https://apps.cer-rec.gc.ca/REGDOCS/Search?txthl=A96429-3%20A%20-%20Expert%20Report%20of%20Lacy%20et%20al%20-%202018%20-%20Final%20-%20A6L5R2

Lacy, R.C., and J.P. Pollak. 2020. VORTEX: A Stochastic Simulation of the Extinction Process. Version 10.4.0. Chicago Zoological Society, Brookfield, Illinois, USA.

Lacy, R.C., P.S. Miller, and K. Traylor-Holzer. 2020. Vortex 10 User's Manual. 1 April 2020 update. IUCN SSC Conservation Breeding Specialist Group, and Chicago Zoological Society, Apple Valley, Minnesota, USA.

Lusseau, D., D.E. Bain, R. Williams, and J.C. Smith. 2009. Vessel traffic disrupts the foraging behavior of southern resident killer whales *Orcinus orca*. Endangered Species Research 6:211-221.

Morris, W.F., and D.F. Doak. 2002. Quantitative Conservation Biology. Theory and Practice of Population Viability Analysis. Sinauer, Sunderland, Mass.

Murray, C.C., L.C. Hannah, T. Doniol-Valcroze, B. Wright, E. Stredulinsky, A. Locke and R. Lacy. 2019. Cumulative Effects Assessment for Northern and Southern Resident Killer Whale Populations in the Northeast Pacific. DFO Can. Sci. Advis. Sec. Res. Doc. 2019/056. x. + 88 p.

Ricklefs, R.E. 1990. Ecology. 3rd ed. Chiron Press, New York.

Shaffer, M.L. 1990. Population viability analysis. Conservation Biology 4:39-40.

Sjögren-Gulve, P., and T. Ebenhard (eds.). 2000. The use of population viability analysis in conservation planning. Ecological Bulletins No. 48.

Vélez-Espino, L.A., J.K.B. Ford, H.A. Araujo, G. Ellis, G., C.K. Parken, and R. Sharma. 2015. Relative importance of Chinook salmon abundance on resident killer whale population growth and viability. Aquatic Conservation 25:756-780.

Ward, E.J., E.E. Holmes, and K.C. Balcomb. 2009. Quantifying the effects of prey abundance on killer whale reproduction. Journal of Applied Ecology, 46:632-640.

EXHIBIT B

ROBERT C. LACY

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Education

B.A., summa cum laude, Biology, Wesleyan University 1977
M.A., Biology, Wesleyan University 1977
Ph.D., Evolutionary Biology (minors: Genetics, Ecology), Cornell University 1982

Positions Held

2019 to present	Senior Conservation Scientist Emeritus, Chicago Zoological Society
1985 to 2019	Senior Conservation Scientist, Chicago Zoological Society
2003 to 2011	Chairman, IUCN Species Survival Commission (SSC) Conservation Breeding Specialist Group
1992 to 1993	Chairman, Dept. of Conservation Biology, Chicago Zoological Society
1982 to 1985	Assistant Professor of Biology, Franklin & Marshall College

Academic Appointments/Graduate Advisory Committees/Postdoctoral Advisees

1985 to present	Chicago Zoological Society, Department of Conservation Biology (Supervised 5 post-doctoral research associates.)
1991 to present	University of Chicago, Lecturer, Committee on Evolutionary Biology (Served on PhD advisory committees for 8 students.)
1999 to present	University of Illinois, Chicago, Adjunct Professor, Department of Biology (Served on PhD advisory committees for 4 students.)
various	External committee member for graduate students at University of Illinois-Urbana, Univ of Maryland, Univ of Wisconsin-Milwaukee, Macquarie Univ, Univ of New South Wales, Monash Univ, South Dakota State Univ, Univ Missouri-St Louis, Univ Montana, Purdue Univ, Otago Univ

Current Research Interests

Interaction among genetic, demographic, and environmental causes of extinction
Modeling the dynamics of linked systems affecting wildlife – including population biology, epidemiology, wildlife harvest, habitat fragmentation, and changes in human populations
Genetic management of wildlife populations
Inbreeding and outbreeding depression

Teaching Experience

Franklin and Marshall College
- Genetics, Vertebrate Biology, Biosocial and Environmental Problems

University of Chicago
- Conservation Biology graduate seminar

Chicago Zoological Society

Lectures on evolution and conservation
Professional schools of the American Zoo and Aquarium Association
Population Management (demography and genetics sections)
Advanced Training Program in the Conservation of Biodiversity
Program coordination, lectures, and mentor for biologists from tropical countries
Escola Superior de Conservação Ambiental e Sustentabilidade (ESCAS, Brazil)
Introduction to Conservation Decision-making
Numerous other workshops on genetic analysis and population management taught to wildlife biologists, zoo managers, and conservation biologists

Professional Societies
Association of Zoos and Aquariums
American Genetic Association
Society for Conservation Biology
Society for the Study of Evolution

Professional Service
Journal advisory boards: Zoo Biology, Conservation Genetics, International Zoo Yearbook
Species Conservation Strategic Planning Task Force, chair (2005-2008), IUCN SSC
Conservation Planning Specialist Group, IUCN SSC (Chair, 2003-2011)
Recent activities include advising US Fish and Wildlife Service, state wildlife agencies, wildlife agencies of other nations (Australia, Canada, Spain, Brazil, Kenya, Indonesia, Malaysia, India, Chile, Peru, Ecuador, South Africa) and international conservation organizations on the management of Florida panther, whooping crane, Sumatran rhinoceros, lion tamarins, lion-tailed macaque, black rhinoceros, Iberian lynx, Humboldt penguin, African penguin, grizzly bear, lowland tapir, and many other species.
Member of IUCN SSC Conservation Genetics Specialist Group
Member of AZA Small Population Management Advisory Group
Advisor to AZA Field Conservation Committee
Conservation Fellow, St Louis Zoo WildCare Institute

Honors
Peirce Award for Excellence in the Sciences, Wesleyan University, 1977
Phi Beta Kappa, 1976
Sigma Xi, 1978
Outstanding Service Awards, American Zoo & Aquarium Assoc (AZA), 1988, 1989, 2001, 2011
President’s Award, Chicago Zoological Society, 2007
IUCN Species Survival Commission Chair’s Citation of Excellence Award, 2008
George B Rabb Award for Conservation Innovation, IUCN Species Survival Commission, 2012
Ulysses S Seal Award for Innovation in Conservation, IUCN Conservation Breeding Specialist Group, 2012
Devra Kleiman Scientific Advancement Award, AZA, 2019
EAZA Lifetime Achievement Award, 2019

Grants

Predoctoral Fellowship. NSF, 1977 - 1980

Doctoral Dissertation - Research in Population Biology. NSF, 1979 – 1981

Faculty research grants. Franklin & Marshall College, 1982 - 1985

Studies of inbreeding depression in *Peromyscus* mice. Institute of Museum Services (IMS), 1985 - 1987, $22,775

Electrophoretic analysis of zoo populations. IMS, 1986 - 1988, $24,995

Studies of outbreeding depression in *Peromyscus* mice. IMS, 1987 - 1989, $25,000

Electrophoretic analyses of endangered species. IMS, 1988 - 1990, $25,000

Chromosomal analysis of endangered species. IMS, 1989 - 1991, $101,347

Predictability of inbreeding depression in insular and mainland populations. NSF, 1991-1994, $182,683

Population Management 2000 software development. AZA Conservation Endowment Fund, 1999, $20,540

Biocomplexity: Models and meta-networks for interdisciplinary research in biodiversity risk assessment. NSF, 2000-2002, $98,000 (with P Nyhus, F Westley, P Miller, and G Ness)

An experimental test of the effects of breeding strategies used in AZA conservation programs. AZA Conservation Endowment Fund, 2001, $42,926

Experimental tests of the effects of captive breeding of wildlife. IMLS, 2002-2005, $75,000.

Pedigree reconstruction to sustain populations. IMLS, 2005-2007, $200,293 (with J. Dubach)

Meta-models as an approach to understanding biocomplexity. Private donor to Chicago Zoological Society, 2006-2010, $100,000

Linking behavioral types and animal "job performance" with population management in zoos. 2009 IMLS National Leadership Planning Grant, $22,535 (with J. Watters and D. Powell)

Incorporating mate choice into breeding recommendations. 2009 IMLS National Leadership Planning Grant, $48,997 (with C. Asa and K. Traylor-Holzer)

RCN: Using metamodels to enable transdisciplinary research for the study of dynamic biological systems under global change. NSF, 2012-2017, $490,905 (with H R Akcakaya, Stony Brook University)

LCP NRDA Dolphin Assessment, sub-contract with Industrial Economics on contract from NOAA. 2014-2015. $118,000 (co-PI with R. Wells)

Building capacity in population modeling for species conservation. Chicago Board of Trade Endangered Species Fund, 2014, $3,000

Assessing conservation strategies for the Panamanian Golden frog. Chicago Board of Trade Endangered Species Fund, 2014, $4,250

Species Conservation Toolkit Initiative, a partnership to design, develop, disseminate, and support software for species risk assessments and conservation planning. Funding from 15 institutions, 2015-2020, $800,000

Impact of allowing mate choice on reproductive success and animal welfare. Association of Zoos & Aquariums, 2016-2017, $11,280 (with L. Miller, T. Snyder, C. Asa, and C. Kozlowski)

Presentations and international workshop participation in 2015

Workshop on computer modeling of disease risk in amphibians, Smithsonian Tropical Research Institute, Panama (organizer and instructor)
Workshop on the use of epidemiological models for wildlife conservation, Auckland, New Zealand (organizer and instructor).
Workshop on the use of metamodels for species conservation assessments and planning, Sydney, Australia (organizer and instructor).
CBSG Strategic Committee, Al Ain, UAE
CBSG Annual Meeting, Al Ain, UAE
Presented paper and led session on "Species Conservation Toolkit Initiative", Association of Zoos and Aquariums (AZA).
Working session, Small Population Management Advisory Group, AZA.
Workshop on the design on ZIMS (Zoological Information Management System) R3, Minneapolis.
Workshop on the effects of plague on the dynamics of prairie dogs and black-footed ferrets, National Black-footed Ferret Conservation Center.
Training on Outbreak model of infectious disease, Chicago Zoological Society (organizer and instructor).
Training on MetaModel Manager software for integrated conservation assessments, Chicago Zoological Society (organizer and instructor).

<u>Presentations and international workshop participation in 2016</u>
Invited presentation on "The what, why, who, where, and when of sustainabilities", Joint TAG Chairs Meeting, World Association of Zoos and Aquariums.
Led workshop on "Computer simulations aren't just for games!" King Scholars Program, Brookfield Zoo.
Led workshop on "Integrating molecular genetic data into pedigree analyses", Chicago Zoological Society.
Invited presentation on "Using Population Viability Analysis to explore impacts of noise on cetaceans", Scientific Committee, International Whaling Commission, Bled, Slovenia.
Workshop on assessing injury to bottlenose dolphins due to PCB contamination of an estuarine system, NOAA and Georgia Dept of Natural Resources, Atlanta, Georgia.
Invited plenary presentation on "Considering human impacts – if not yet the humans – in species risk assessments", IUCN SSC Conservation Breeding Specialist Group, Puebla, Mexico.
Led workshop on "MetaModels for interacting species (multi-species PVAs and conservation planning)", IUCN SSC Conservation Breeding Specialist Group, Puebla, Mexico.
Dept of Fisheries and Oceans Canada, presentation on "Predicting responses of St. Lawrence beluga to environmental change and anthropogenic threats to orient effective recovery actions".
University of Maine – Machias, invited talk on "Building tools for wildlife conservation".

<u>Presentations and international workshop participation in 2017</u>
Tools for managing island populations. Presented to New Zealand Department of Conservation.
One Plan Approach: Working together for species conservation. Presented at Latin America Zoo Association (ALZPA) annual conference. Havana, Cuba

Training in advanced techniques for population modeling with Vortex. Presented at AZA Reproductive Management Center, St Louis, Missouri
Overview of Species Conservation Toolkit Initiative. IUCN SSC Conservation Planning Specialist Group annual meeting, Berlin, Germany
Outbreak software for modeling infectious disease. Presented at Disease Risk Assessment Workshop. IUCN Conservation Planning Specialist Group, Sao Paulo, Brazil

Presentations and international workshop participation in 2018
Training in advanced techniques for population modeling with Vortex. Seattle, WA
Workshop on "Using Outbreak software for modeling infectious disease in wildlife populations". Prague, Czech Republic
Synthesis workshop on "Using metamodels to enable transdisciplinary research for the study of dynamic biological systems under global change." White Oak, Florida

Presentations and international workshop participation in 2019
Population and Habitat Viability Assessment for the Humboldt penguin. Lima, Peru
Workshop projecting the possible outcomes and mitigation strategies if Ebola infects Mountain Gorilla populations. Washington, DC
Population Viability Analysis of the Florida ScrubJay. Archbold Biological Station and Kennedy Space Center, Florida
EAZA (European Association of Zoos and Aquaria) annual meeting, Valencia, Spain
Strategic Planning, IUCN SSC Conservation Planning Specialist Group, Minneapolis, Minnesota
Strategic Planning, Species Conservation Toolkit Initiative, Brookfield, Illinois

Publications
Lacy, R.C., C.B. Lynch and G.R. Lynch. 1978. Developmental and adult acclimation effects of ambient temperature on temperature regulation of mice selected for high and low levels of nest-building. Journal of Comparative Physiology B 123:185-192.
Lacy, R.C. 1978. Dynamics of t-alleles in *Mus musculus* populations: Review and speculation. The Biologist 60:41-67.
Lacy, R.C. 1979. The adaptiveness of a rare male mating advantage under heterosis. Behavior Genetics 9:51-54.
Lacy, R.C. and C.B. Lynch. 1979. Quantitative genetic analysis of temperature regulation in *Mus musculus*. I. Partitioning of variance. Genetics 91:743-753.
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Naturalist 121:489-512.
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Lacy, R.C. 1984. The evolution of termite eusociality: Reply to Leinaas. American Naturalist 123:876-878.
Hayssen, V. and R.C. Lacy. 1985. Basal metabolic rates in mammals: Taxonomic differences in the allometry of BMR and body mass. Comparative Biochemistry and Physiology 81A:741-754.
Hayssen, V., R.C. Lacy and P.J. Parker. 1985. Metatherian reproduction: Transitional or transcending? American Naturalist 126:617-632.
Lacy, R.C. 1985. Evidence that group selection counters the evolution of sexual dimorphism. Evolutionary Theory 7:173-177.
Lacy, R.C. 1985. Some genetic considerations for the management of captive populations suggested by computer simulations. AAZPA 1985 Annual Proceedings, 627-630.
Lacy, R.C. and C.E. Bock. 1986. The correlation of range size and local abundance of some North American birds. Ecology 67:258-260.
Lacy, R.C. 1987. Loss of genetic diversity from managed populations: Interacting effects of drift, mutation, immigration, selection, and population subdivision. Conservation Biology 1:143-158.
Lacy, R.C. 1987. Further genetic and demographic analyses of small rhino populations. Pachyderm (Newsletter of the African Elephant and Rhino Specialist Group) No. 9, pp. 16-19.
Lacy, R.C. 1988. A report on population genetics in conservation. Conservation Biology 2:245-247.
Lacy, R.C. 1988. Genetic variability in captive stocks: Assessing past loss, present status, and future outlook. AAZPA 1988 Annual Proceedings 113-121.
Lacy, R.C., M.L. Foster, and the Primate Department Staff. 1988. Determination of pedigrees and taxa of primates by protein electrophoresis. International Zoo Yearbook 27:159-168.
Lacy, R.C. 1988. Conservation genetics at Brookfield Zoo and the Brookfield-Melbourne genetics research programme. Bulletin of Zoo Management 26:27-29.
Lacy, R.C. and T.W. Clark. 1989. Genetic variability in black-footed ferret populations: Past, present, and future. Pages 83-103 in U.S. Seal, E.T. Thorne, M.A. Bogan, and S.H. Anderson (eds.), Conservation Biology and the Black-Footed Ferret. Yale University Press, New Haven.
Lacy, R.C. 1989. How many pairs are needed on the ark? Bison 4:24-28.
Lacy, R.C. 1989. Analysis of founder representation in pedigrees: Founder equivalents and founder genome equivalents. Zoo Biology 8:111-124.
Lacy, R.C, Flesness, N.R., and Seal, U.S. 1989. Puerto Rican parrot population viability analysis. Report to the U.S. Fish and Wildlife Service. IUCN SSC Captive Breeding Specialist Group, Apple Valley, Minnesota.
Seal, U.S. and R.C. Lacy. 1989. Florida panther population viability analysis. Report to the

U.S. Fish and Wildlife Service. IUCN SSC Captive Breeding Specialist Group, Apple Valley, Minnesota.

Paine, F.L., J.D. Miller, G. Crawshaw, B. Johnson, R. Lacy, C.F. Smith III, and P.J. Tolson. 1990. Status of the Puerto Rican crested toad. International Zoo Yearbook 28:53-58.

Maguire, L.A. and R.C. Lacy. 1990. Allocating scarce resources for conservation of endangered subspecies: Partitioning zoo space for tigers. Conservation Biology 4:157-166.

Brewer, B.A., R.C. Lacy, M.L. Foster, and G. Alaks. 1990. Inbreeding depression in insular and central populations of *Peromyscus* mice. Journal of Heredity 81:257-266.

Maguire, L.A., R.C. Lacy, R.J. Begg, and T.W. Clark. 1990. An analysis of alternative strategies for recovering the eastern barred bandicoot in Victoria. Pages 147-164 in T.W. Clark and J.H. Seebeck (eds.), The Management and Conservation of Small Populations. Chicago Zoological Society, Brookfield, Illinois.

Lacy, R.C. and T.W. Clark. 1990. Population viability assessment of the eastern barred bandicoot in Victoria. Pages 131-146 in T.W. Clark and J.H. Seebeck (eds.), The Management and Conservation of Small Populations. Chicago Zoological Society.

George, G.G., J. Dixon, G. Challis, and R.C. Lacy. 1990. Taxonomy and palaeontology of the eastern barred bandicoot. Pages 33-46 in T.W. Clark and J.H. Seebeck (eds.), The Management and Conservation of Small Populations. Chicago Zoological Society.

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Lindenmayer, D.B., V.C. Thomas, R.C. Lacy, and T.W. Clark. 1991. Population Viability Analysis (PVA): The concept and its applications, with a case study of Leadbeater's Possum, *Gymnobelideus leadbeateri* McCoy. Report to the Forest and Timber Inquiry (Resource Assessment Commission), Consultancy Series No. FTC91/18, Canberra, Australia. 170 pp.

Clark, T.W., G.N. Backhouse, and R.C. Lacy. 1991. The population viability assessment workshop: A tool for threatened species management. Endangered Species Update 8:1-5.

Clark, T.W., G.N. Backhouse, and R.C. Lacy. 1991. Report of a workshop on population viability assessment as a tool for threatened species management and conservation. Australian Zoologist 27:28-35.

Lacy, R.C. 1991. Zoos and the surplus problem: An alternative solution. Zoo Biology 10:293-297.

Johnston, L.A. and R.C. Lacy. 1991. Utilization of sperm banks to maintain genetic diversity in captive populations of wild cattle. Pages 107-118 in D.L. Armstrong and T.S. Groves (eds.), Wild Cattle Symposium Proceedings. Henry Doorly Zoo, Omaha, Nebraska.

Seal, U.S., R.C. Lacy, K. Medley, R. Seal, and T.J. Foose. 1991. Tana River Primate Reserve Conservation Assessment Workshop Report. IUCN SSC Captive Breeding Specialist Group, Apple Valley, Minnesota.

Mirande, C., R. Lacy, and U. Seal. 1991. Whooping crane (*Grus americana*) conservation viability assessment workshop report. IUCN SSC Captive Breeding Specialist Group, Apple Valley, Minnesota.

Foose, T.J., R.C. Lacy, R. Brett, and U.S. Seal. 1991. Kenya black rhinoceros metapopulation workshop report. IUCN SSC Captive Breeding Specialist Group, Apple Valley,

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PMx: Software for demographic and genetic analysis and management of populations. (Developed jointly with J. Ballou and J.P. Pollak). Used to guide management of captive populations of more than 1000 species globally.

Vortex: Simulation of interacting genetic, demographic, and environmental causes of extinction in small, isolated populations interconnected by occasional migration. Used by conservation and wildlife biologists to assist in the analysis and management of wild populations of 100s of species in more than 70 countries.

Vortex Adaptive Manager. Software for guiding adaptive management of wildlife populations.

Outbreak: Epidemiological simulation for modeling infectious disease. (Developed with J.P. Pollak, P.S. Miller, et al.)

MetaModel Manager: Flexible modeling platform for linking simulation models representing diverse processes (such as species interactions, habitat change, climate change, disease, and social systems) to provide more holistic risk assessments for wildlife populations. (Developed with J.P. Pollak.)