Salamander Disease in the Wildlife Trade

Background on wildlife trade

Increasing global connectedness of human societies has facilitated the spread of pathogens through wildlife trade (e.g., SARS-CoV-2, Monkeypox virus, and the amphibian fungal pathogen *Batrachochytrium dendrobatidis* [*Bd*]). Wildlife trade is a burgeoning industry, doubling in the last decade to an estimated 2.5 million live animals traded annually, primarily as exotic pets, involving >180 nations and valued at >$300 billion USD (Smith et al. 2017). Tremendous potential for introduction of pathogens to wild populations outside its native range (i.e., spillover; Fig. 1) exists for most nations because live animals can be traded as exotic pets without animal health certificates. Moreover, the network of suppliers, distributors, and retailers that make up the exotic pet trade (Fig. 1) provide ideal conditions for amplifying imported pathogens (e.g., high animal density, stressful husbandry conditions).

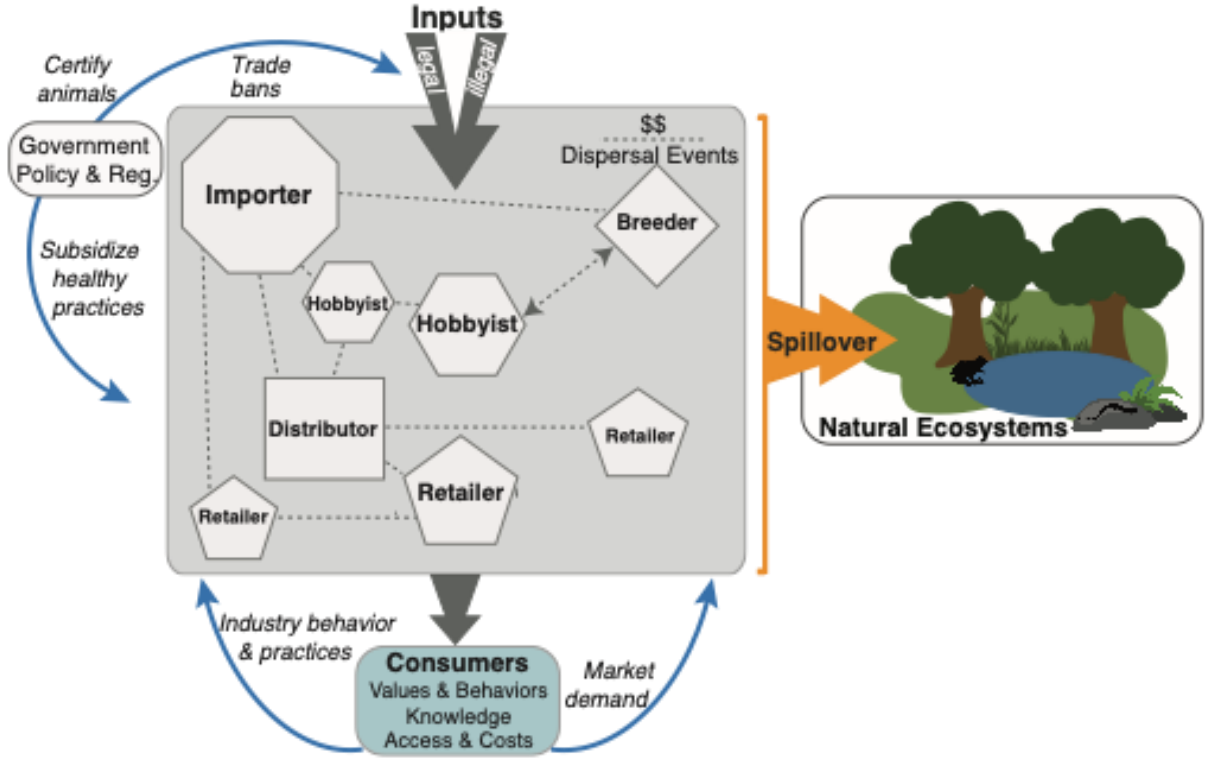

Figure 1. Network of amphibian trade and representation of pathogen spillover (modified from Gray et al. 2020 NSF grant proposal).

Disease networks for wildlife trade are characterized as a set of nodes (e.g., suppliers, distributors, retailers, consumers) in which pathogens and hosts can persist, and pathways through which both can disperse via economic transactions. Identifying factors that contribute to pathogen amplification (or reduction) in disease networks is fundamental to preventing spillover. Unlike wildlife disease networks in natural systems, pet industry and consumers can directly

affect within- and between-node processes and host health. Additionally, if pathogen spillover occurs, loss of biodiversity in the natural system could lead to reduced ecosystem services (e.g., insect control by salamanders) provided by native wildlife and result in unexpected negative feedbacks on society.

In order to investigate which factors alter pathogen amplification in the trade network and the likelihood of pathogen spillover we must collect and analyze social science or human dimensions data. In this activity we will focus on a relatively new fungal pathogen of salamanders *Batrachochytrium salamandrivorans*, or *Bsal*.

Amphibian fungal pathogens

Batrachochytrium salamandrivorans (*Bsal*) was first identified in 2013 (Martel et al.) from a wild salamander die-off in Europe. Both *Bsal* and *Batrachochytrium dendrobatidis* (*Bd*) – first identified in 1998 (Berger et al.) – are species of chytrid fungi. *Bd* can infect and kill all orders of amphibians and has a widespread global distribution. *Bsal* is native to Asia and although it has been detected on some frog species, the disease is restricted to salamanders. *Bsal* is an emerging infectious disease that is at an early stage of global transmission (only detected in Europe and Asia). Wildlife scientists and managers aim to contain or treat infected animals in captive situations to prevent spillover.

Often animals can carry chytrid fungi for weeks or months without any visible signs of disease (visible disease is also known as chytridiomycosis), during which time they are infectious to other animals. Chytrid fungi can be spread by direct contact between animals or from contaminated materials, such as water, equipment, soil, gravel, aquatic plants, etc. These fungi can persist in the environment without amphibians for up to several weeks. For both *Bd* and *Bsal*, non-invasive skin swabs can be used to diagnose infection. Treatments are available for sick animals and to eradicate infection from animals carrying chytrid fungi.

North American salamanders

North America is a global hotspot for salamander diversity, home to nearly 50% of all species. Salamanders play key ecosystem roles, as they are centrally nested in food webs and occur both in water and on land. We use salamanders as metrics of environmental change, and they are critical to biomedical research on limb regeneration and other human health benefits. Numerous threats affect amphibians like salamanders, including diseases like *Bsal*. Experimental studies show that *Bsal* can kill North American salamanders. Although *Bsal* is not known to occur in North America as of September 2020, pathways for its entry do exist via wildlife trade networks. Asian salamander species are held in international captive collections and are common pets; of the nearly 3 million salamanders imported to the U.S. over the past decade, >85% were Asian salamanders. Interagency and international collaboration and action will be essential to prevent or reduce the risk of *Bsal* introduction to the United States, Canada, and Mexico.

One step towards prevention was taken in January 2016 by the U.S. Fish and Wildlife Service (USFWS). They listed 201 species of salamanders as “injurious wildlife species”, some of which are currently in the pet trade, under the Lacey Act. The interim rule prohibits importation or interstate transport of the listed salamander species (live, dead, or parts) in the absence of a permit for medical, scientific, zoological and educational activities.

Activity: Stakeholder Analysis

Stakeholders are a group of people or individuals that have an interest or 'stake' in a particular issue. Stakeholders can either affect or be affected by the issue. In the case of preventing *Bsal* spread into North America, a range of stakeholders are involved:

State/federal agency biologists: Government agencies at the state or federal level work to conserve natural resources. Wildlife biologists who work for these agencies restore, protect, and manage wildlife and their ecosystems. Most ecosystem management takes place on public lands (owned by the government), although many agencies have private land partnerships. Species that can be hunted or fished are often the primary focus for state agency biologists because of their funding structure (i.e., revenue from hunting and fishing licenses and gear support the agency).

Academic scientists: Academic scientists are typically university faculty or research staff. They have some similar characteristics to wildlife biologists in that they are concerned with native species loss and ecosystem impacts, but their job responsibilities are often focused on research. They have expertise in different scientific disciplines (e.g., ecology or herpetology). Academic scientists are often the first ones to identify new species of pathogens, such as *Bsal*, and conduct basic and applied scientific research on these species. Scientists may also work outside of academia (e.g., industry and non-profits).

Amphibian pet owner: A person who keeps an amphibian as a pet in captivity. Sometimes referred to as the 'consumer' when discussing market supply and demand. An amphibian pet owner may also be referred to as a 'hobbyist'. Owners may keep native amphibian species or exotic / non-native species as pets.

Amphibian breeder or hobbyist: A business that breeds and raises amphibians in captivity for sale as pets. These businesses may arise initially from a hobbyist's interest in raising amphibians. The source of amphibians for breeders may be wild caught and/or captivity. These facilities often sell online only directly to the consumer, or through a distributor to a retailer. They are a critical component of the pet industry in that they source animals, although the revenue from live animals is often complemented by sales of other pet supplies. Some breeders also provide educational material (e.g., videos) to consumers for how to care for their pets.

Pet store / Retailer: Pet stores and retail businesses sell live pets and pet supplies directly to pet owners. They are often a physical store that consumers can visit in-person. They must purchase their live animals and supplies from amphibian breeders.

Outdoor recreationist: People who recreate in the outdoors. They may enjoy and value the outdoors for the diversity of wildlife and plants they observe or for other benefits. In certain areas of the U.S. where amphibian diversity is very high, visitors may seek out those areas specifically to view this diversity.

References

Berger L, Speare R, Daszak P, Green DE, Cunningham AA, Goggin CL, et al. 1998. Chytridiomycosis causes amphibian mortality associated with population declines in the rain forests of Australia and Central America. *Proc Natl Acad Sci USA.* 95:9031–6. doi: 10.1073/pnas.95.15.9031

Martel A, Spitzen-van der Sluijs A, Blooi M, Bert W, Ducatelle R, Fisher MC, et al. 2013. *Batrachochytrium salamandrivorans* sp. nov. causes lethal chytridiomycosis in amphibians. *Proc Natl Acad Sci USA.* 110:15325–9. doi: 10.1073/pnas.1307356110

Ossiboff RJ, Towe AE, Brown MA, Longo AV, Lips KR, Miller DL, Carter ED, Gray MJ and Frasca S Jr. 2019. Differentiating *Batrachochytrium dendrobatidis* and *B. salamandrivorans* in Amphibian Chytridiomycosis Using RNAScope® *in situ* Hybridization. *Front. Vet. Sci.* 6:304. doi: 10.3389/fvets.2019.00304

Smith, KM, Zambrana-Torrelio C, White A. *et al.* 2017. Summarizing US Wildlife Trade with an Eye Toward Assessing the Risk of Infectious Disease Introduction. *EcoHealth* **14,** 29–39. https://doi.org/10.1007/s10393-017-1211-7

Links to other useful resources:

https://www.salamanderfungus.org/wp-content/uploads/2015/11/Amphibian-disease-alert_June-2015.pdf

https://www.salamanderfungus.org/wp-content/uploads/2015/11/BsalBrief-1-Page-Flier2015.pdf

https://www.fws.gov/injuriouswildlife/salamanders.html

https://www.fws.gov/injuriouswildlife/pdf_files/Bsal_Q_A_Document_FINAL.pdf

Conceptual Model for Project Planning

Adapted by J. Sevin from Open Standards for Conservation Practice [https://cmp-openstandards.org/]

Terms:
Biodiversity Scope: Broad parameters of project; the thematic and geographic focus
Conservation Target: Identify the specific goal(s); should be measurable and achievable
Threat: Direct human action or unsustainable use which is impacting target
Driver: a factor that contributes to or causes the direct threats; a.k.a indirect threat
Intervention: an action or opportunity which can reduce, prevent, mitigate or alter a Driver

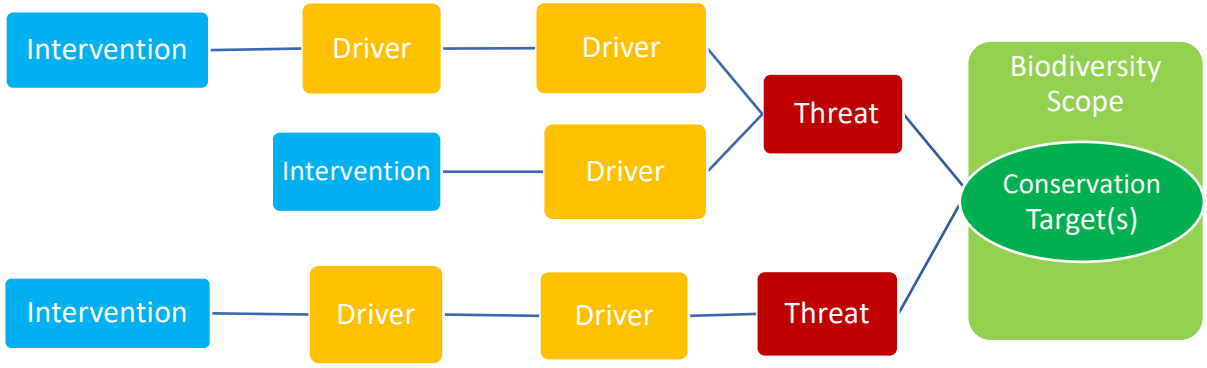

Figure 1. Example of framework of the conceptual model showing factors and their relationship to each other. This conceptual model is an adaptation from the Open Standards for Conservation.

Figure 2. Example of a simplified conceptual model to address the issue of deforestation of tropical forests in Western Brazil.

IRB Project Proposal

You are to develop a social science project proposal that will inform/guide one of the Conservation Interventions from your conceptual model related to amphibians. Your final proposal must address the following items:

1. Project title

2. Describe the scientific purposes of the project (why), including study aims and hypotheses to be tested.

3. Describe the research methods (how, what, when, where) that will be used, including research design, type of measures, procedure, techniques, when and where conducted, and more. If the project uses self-report methods, such as surveys, questionnaires, and interviews, copies of the actual items used must be submitted to the IRB.

4. Describe the study participants (who) including approximate anticipated number and any specific characteristics, such as age, geographic region, economic status, etc. Note if they are members of any identified vulnerable population, any factors that may affect the ethical acceptability or conduct of this research for this population, and describe steps taken to minimize the possibility of coercion or undue influence. Describe how you will recruit study subjects. The word-for-word recruiting messages are required. Insert them here or as a separate document with this research form.

5. Detail the data management and analysis plan. How will data be collected, stored and managed? How will any personal identifying information be protected? Describe how the data will be analyzed.

6. Describe the expected output or outcomes and how the findings will be disseminated.