

2022

North American *Bsal* Implementation Plan



North American
Bsal Task Force

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Cover photo: Swabbing the skin of an Eastern Newt (*Notophthalmus viridescens*) to test for the presence of *Bsal*.
Photo credit: Todd Amacker.

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Update: 13 October 2020

Summary

The document “A North American Strategic Plan to Prevent and Control Invasions of the Lethal Salamander Pathogen *Batrachochytrium salamandrivorans*” (also referred to as the “*Bsal* Strategic Plan”, available at salamanderfungus.org) is the result of ongoing collaborations of members of the North American *Bsal* Task Force and partners. The overarching objective of the *Bsal* Strategic Plan is to provide interdisciplinary scientific and managerial guidance to forestall emergence of *Bsal* in North America. This is a complex objective that has led to the development of a Technical Advisory Committee (TAC) and multiple *Bsal* working groups. The TAC serves an oversight function for working groups and provides communication with key partners but also takes on overarching activities, such as collaborative projects among Task Force members and partners. Working groups are convened to advance knowledge relative to eight disciplinary themes and their integration: Response & Control; Diagnostics; Research; Decision Science; Surveillance & Monitoring; Data Management; Outreach & Communication; and Clean Trade.

Actions of the TAC and working groups are developed in a hierarchical fashion outlined here in the North American *Bsal* Implementation Plan. First, the Framework of Actions summarizes the initial breadth of the Task Force’s aims as nine general intention statements. Second, goals of the TAC and working groups are articulated as statements that frame thematic activities specific to each group. Each of the nine statements in the Framework of Actions tiers to one or more goals shared among groups. Third, priorities of the TAC and working groups are specific tasks or activities undertaken under the theme of a goal. Priorities are the iterative steps that have been identified to advance achievement of the goal and may represent separate studies undertaken by working group members or subgroups or represent stages in the development of programmatic operations to advance *Bsal* response activities. As the *Bsal* Task Force has been in operation since 2015, some initial goals’ priority tasks have been completed. These completed tasks are briefly summarized below as well as the list of priorities in development at this time. The North American *Bsal* Implementation Plan is a living document intended to track current goals, priorities, and their separate tasks across working groups as well as for the TAC and *Bsal* Task Force as an overarching leadership cadre. This Implementation Plan is written as Appendix 5 of the *Bsal* Strategic Plan, with updates to be posted on partner web pages (e.g., salamanderfungus.org; amphibiandisease.org; Partners in Amphibian and Reptile Conservation, national Disease Task Team web page). Periodic updates are expected at annual or longer time scales and are noted by the date on the first page.

Overview

The North American *Bsal* Task Force was initiated in June 2015 to address the complex facets of potential *Batrachochytrium salamandrivorans* (*Bsal*) emergence in North America and the projected dire outcomes that could ensue for native amphibian fauna because of this pathogen (Martel et al. 2014, Gray et al. 2015, Yap et al. 2015, Richgels et al. 2016). The document “A North American Strategic Plan to Prevent and Control Invasions of the Lethal Salamander Pathogen *Batrachochytrium salamandrivorans*” (also referred to as the *Bsal* Strategic Plan; salamanderfungus.org) summarizes interdisciplinary scientific and managerial guidance for a successful response to the detection of *Bsal* in North America. The *Bsal* Strategic Plan provides additional detail on the amphibian chytrid fungus *Bsal* (the pathogen that can cause the disease *Bsal* chytridiomycosis in some amphibians); emergence of the disease *Bsal* chytridiomycosis in Europe; current knowledge of the Asian origin of *Bsal*; and the origin, structure (Fig. 1), and aims of the *Bsal* Task Force.

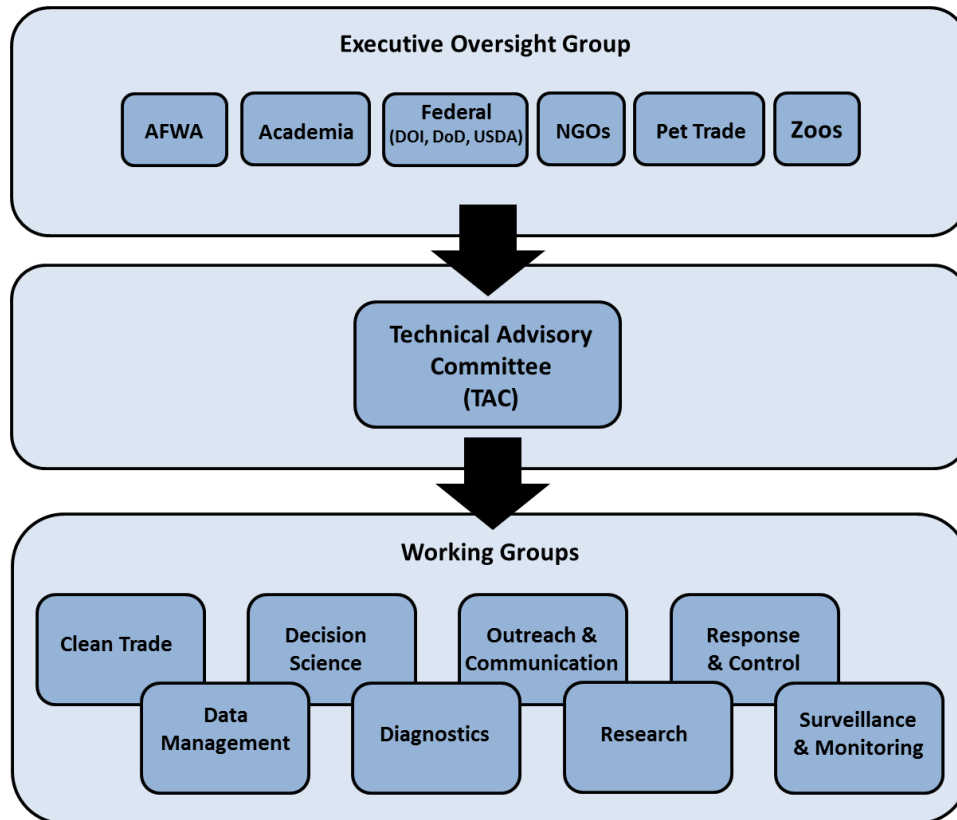


Figure 1. Structure of the North American *Bsal* Task Force.

The Implementation Plan of the *Bsal* Strategic Plan is organized in a three-step hierarchical fashion. First, the **Framework of Actions** (Box 1) provides intention statements to capture the overarching breadth of the initial objectives of the Task Force. Second, **goals** describe the broad thematic aims undertaken by 1) the *Bsal* Technical Advisory Committee (TAC), the leadership body of the Task Force and its key partners, and 2) the working groups, assembled to address

separate disciplinary or operational topics in depth (Fig. 1). Goals of the TAC and working groups may tier to statements in the Framework of Actions. Currently, there are eight working groups: Response & Control; Diagnostics; Research; Decision Science; Surveillance & Monitoring; Data Management; Outreach & Communication; and Clean Trade. Each working group has an objectives statement to define its scope, under which its goals define thematic activities. Third, to achieve the broad goals of the different groups, more specific **priorities** are developed. Priorities are independent task statements or activities that aid in a stepwise advancement of goals. Priorities may align with specific studies or operational procedures to advance the efficacy of the *Bsal* Task Force.

The North American *Bsal* Implementation Plan describes the objectives, goals, and priorities of TAC activities with its partners and each working group. Since 2015, several tasks have been addressed, and new goals, priorities and tasks have been developed over time. For each working group, a summary of completed tasks and current goals and priorities is provided.

The North American *Bsal* Task Force is a non-affiliated partner-based organization. To implement the goals, priorities, and tasks outlined in the *Bsal* Strategic Plan and Implementation Plan, in-kind resources of the myriad partners in North America (e.g., employers of Task Force members) are used. These resources include personnel time to advance various activities and, in some cases, operating and facility costs of projects undertaken. The *Bsal* Task Force is grateful for this support as well as for the volunteer hours donated to the Task Force's efforts. However, implementation of some work described below is heavily reliant upon obtaining external grants and agreements. As the work depending on funding from grants and agreements is an integral part of selected goal and priority implementation, the financial planning that accompanies those aims is briefly included in this document. In addition, as implementation decisions are weighed with consideration of limited available resources, the relative ranking of the importance of goals and priorities may be highly relevant. General ranks of Urgent, High, and Medium are provided for this purpose.

The North American *Bsal* Implementation Plan is intended to adapt over time as tasks are completed, priorities are met, new information is forthcoming, and new goals and priorities are identified by the TAC and the working groups. The Implementation Plan will be updated on associated web portals (e.g., salamanderfungus.org; amphibiandisease.org; [Partners in Amphibian and Reptile Conservation national Disease Task Team](#)) and dated accordingly. Periodic updates are expected at annual or longer time scales.

Box 1. Framework of Actions

Upon organization of the *Bsal* Task Force, nine guiding principles for strategic planning along several themes were developed to forestall *Bsal* emergence in North America. This Framework of Actions led to the development of eight Working Groups and associated collaborations among researchers, managers, industry, and other partners across North America.

1. Prevent invasion of *Bsal* into North America by encouraging stakeholders to work toward a clean trade program for amphibians that certifies individuals in trade are free of *Bsal* infection.
2. Develop and encourage use of the Rapid Response Plan (Appendix 4 in the Strategic Plan), which can be customized to meet local needs, to contain a *Bsal* outbreak.
3. Develop a network of diagnostic laboratories that can run validated tests to detect the presence of *Bsal* in animal or environmental samples in a timely manner.
4. Test for the occurrence of *Bsal* in Canada, Mexico, and the United States in the field and in captivity, reduce the risk of spillover from captive to wild amphibians, and reduce the likelihood of humans playing a role in the inadvertent translocation of *Bsal* within North America.
5. Advance the understanding of the risk of *Bsal* introduction to North America and assess the invasion risk of this deadly pathogen to native North American amphibians through decision science analyses, research, and development of a common repository for aggregating and managing *Bsal* surveillance data.
6. Develop effective, scientifically justified prevention and mitigation strategies that prevent *Bsal*-associated infections and mortality.
7. As evidence-based *Bsal* response and management actions are developed, identify expedited pathways for permitting actions and facilitate regulatory processes to implement mitigation measures.
8. Work with partners to compile and disseminate surveillance and research results via social media, accessible web portal databases, and newsletter articles.
9. Build a network of partners that can communicate updates on *Bsal* developments and alert the public and scientific community if *Bsal* is detected in Canada, Mexico, or the United States.



Eastern Red-backed Salamander (*Plethodon cinereus*). © Alberto López.

A. *Bsal* Technical Advisory Committee (TAC)

Objective: To serve as an integrated leadership body of the North American *Bsal* Task Force in collaboration with key partners, framing the scope and intent of the activities undertaken by the Task Force as a whole and as an advisory panel for working groups and ad-hoc subgroups.

Leads: María Forzán (Long Island University, NY, USA, current) and Molly Bletz (University of Massachusetts, MA, USA, in-coming)

Past Leads: Dede Olson (US Forest Service, OR, USA); Jennifer Ballard (formerly of US Fish and Wildlife Service, AR, USA); Mike Adams (US Geological Survey, OR, USA); Reid Harris (formerly of James Madison University and Amphibian Survival Alliance, VA, USA); Jake Kerby (University of South Dakota, SD, USA); and Matt Gray (University of Tennessee, TN, USA).

Canada Liason: Cynthia Pekarik (Environment and Climate Change Canada, QC, Canada)

Past Canada Liasons: Jennifer Provencher (Science and Technology Branch, ON, Canada); Sam Iverson (Canadian Wildlife Service, QC, Canada)

Mexico Liasons: Gabriella Parra-Olea and Eria Rebollar (Universidad Nacional Autonoma de México, Mexico)

The structure of the North American *Bsal* Task Force centers upon the Technical Advisory Committee (TAC) and the eight working groups (Fig. 1). The TAC is populated by the working group leads; representatives from Canada, Mexico, and the United States; and representatives from partner groups, including different government agencies, the IUCN Amphibian Survival Alliance (ASA), the Pet Industry Joint Advisory Council (PIJAC), and Partners in Amphibian and Reptile Conservation (PARC). The roles of TAC members vary considerably, with strategic surveillance, research, and proactive planning being tri-lateral priorities across the three countries and advances in biosecurity procedures being contributed by PARC's national and regional Disease Task Teams.

The TAC meets monthly by conference call, with a focus on new tasks of the TAC, progress reports on ongoing tasks, and round-robin reporting by working group leads and partners. New items have included actions or projects to be assigned or delegated to a subset of members, opportunities for products and grant proposals, subgroup activities with partners, and discussion of communication, outreach, and networking needs. A lead for the TAC is rotated each year,

adding broader perspectives to Task Force activities and ensuring shared leadership of developing products. The incoming and past leads help to transition work and knowledge. Decisions of the TAC are made by consensus. In particular, the TAC identifies novel implementation actions or priorities from new *Bsal* information forthcoming from the international *Bsal* research and management community, working groups, and partners.

Goal A.1. Leadership of the *Bsal* Task Force and ensuring progress toward the Framework Actions.

Rank: Urgent

Rationale: Coordinated oversight of the *Bsal* Task Force by working group leads and partners will aid inter-group communication and identification of strategic gaps in development of a program to forestall *Bsal* transmission to, or potential translocation within, North America.

Management Relevance: The Framework of Actions (Box 1) of the *Bsal* Task Force were identified as the initial scope of interdisciplinary work needed to understand and forestall potential *Bsal* emergence in North America and protect our natural heritage biodiversity into the future. To address these actions and additional concerns that have been raised in a coordinated fashion, the TAC and its partners and ad-hoc subgroups have taken on a variety of specific tasks that have helped the *Bsal* Task Force to be better defined and developed (nine current priorities listed below). The Urgent rank of this goal has expedited development of numerous strategic actions, 2015 to present, raising awareness among natural resource managers and expediting response processes among both management and science communities.

Financial Needs: In-kind support from member agencies and institutions for personnel time and travel; grants for publication costs, symposia, and workshops.

Priority A.1.1: Expand North American collaborations for *Bsal* science and management with broader academic, governmental, non-governmental, and conservation interest groups.

Priority A.1.2: Foster inclusivity and diversity in the North American *Bsal* Task Force structure, participants, and leadership, including enhancing representation across Canada, Mexico, the United States, and the First Nations and Indigenous peoples of North America; geographic or cultural diversity within nations; disciplinary expertise, including epidemiology, wildlife biology, wildlife health and veterinary sciences, ecology, trade, and zoos and aquariums; representation across employment sectors, including academic and research institutions, government agencies, non-governmental or non-profit organizations, and business and industry organizations; and additional human dimensions, such as gender, age, and ethnicity.

Priority A.1.3: Organize international *Bsal* symposia with European partners to focus on communication of science and management directions in North America and Europe, two continents with heightened *Bsal* emergence concerns.

Priority A.1.4: Organize focused workshops, in conjunction with international symposia or other relevant meetings, to leverage assembly of interested experts for advancing

knowledge across the spectrum of the framework of actions in two continents with heightened *Bsal* emergence concerns, North America and Europe.

Priority A.1.5: Formally publish the North American *Bsal* Strategic Plan with online access for facilitate communication and referencing capability.

Priority A.1.6: Distinguish the North American *Bsal* Implementation Plan from the *Bsal* Strategic Plan and *Bsal* annual reports, which iterate annual achievements and new activities.

Priority A.1.7: Update the *Bsal* Task Force website (salamanderfungus.org) to provide easier access to information and expand web pages per working group.

Priority A.1.8: Leverage expansion of *Bsal* communication and outreach efforts with other scheduled events and opportunities, including Amphibian Week, which is planned by PARC and held annually during the first full week of May.

Priority A.1.9: Provide support to all working groups as needed but especially for the newest working group, the Clean Trade Working Group, as it navigates assembly and task identification across the United States and Canada.

Background: Examples of past TAC implementation priorities under Goal A.1 that have already been completed and have advanced the Task Force development and mission include 1) an establishment report of the *Bsal* Task Force (Grant et al. 2015); 2) an overarching decision science framework for addressing *Bsal* emergence in North America, a product led by the Decision Science Working Group with broad collaboration by the TAC and partners (Grant et al. 2017; described further below); 3) completion of the *Bsal* Rapid Response Plan Template (Appendix 4, *Bsal* Strategic Plan), a product led by the Response & Control Working Group under advisement of the TAC and consultation with partners (Appendix 4 of the *Bsal* Strategic Plan; described further below); 4) a scenario-building exercise of responses if *Bsal* were to be detected in North America, led by US Geological Survey scientists with a subgroup of TAC members and partners (Hopkins et al. 2018); 5) a position paper describing the benefits of early release of information regarding *Bsal* occurrence in novel areas without adverse implications for later scientific publication opportunities of principal investigators involved in the discovery (Adams et al. 2018); 6) the North American *Bsal* Strategic Plan, the overarching document within which this Implementation Plan is Appendix 5 and which describes *Bsal* and its discovery, the Task Force initiation and structure, and the scope and interests of working groups; 7) *Bsal* Task Force annual reports of achievements, developed with the Outreach & Communication Working Group (2016 to present, available at salamanderfungus.org); and 8) development of early drafts of this *Bsal* Implementation Plan.

TAC members, in association with key partners, have developed products that contribute to TAC and working group goals. In particular, PARC's national Disease Task Team includes *Bsal* TAC members and has taken on an important additional communication and outreach function for the North American *Bsal* Task Force. For example, they have developed: 1) a call to action for *Bsal* in North America (Gray et al. 2015); 2) a one-page briefing paper on *Bsal* (parcplace.org/wp-content/uploads/2017/08/BsalBrief.pdf); 3) guidance for herpetological pathogen surveillance, with *Bsal* applications specified (Gray et al. 2017); 4) a Herpetofaunal Disease Alert System (Gray et al. 2018; parcplace.org/resources/parc-disease-task-team/) to help with a rapid response to disease-related die-offs in North America, including potential *Bsal*-related die-offs; and 5) biosecurity guidance to forestall transmission of pathogens, including

Bsal (Julian et al. 2020). In addition, in 2019, *Bsal* TAC members and partners organized the First North American *Bsal* Symposium, which was held at the joint annual meetings of The Wildlife Society and the American Fisheries Society in Reno, Nevada (Pereira et al. 2020; videos of invited talks: <https://itunes.apple.com/itunes-u/ut-forestry-wildlife-fisheries/id494866284>). More recently, the TAC held a virtual conference, the North American *Batrachochytrium salamandrivorans* Task Force Inaugural Annual Meeting, where overviews of the goals and activities of the Task Force were presented to members, wildlife managers, and members of the public (<https://www.salamanderfungus.org>; accessed 10 May 2021).

The TAC also has helped in an advisory capacity with decisions regarding transitioning priorities of *Bsal* working groups as initial tasks were completed. For example, after the Rapid Response Plan Template (Appendix 4, *Bsal* Strategic Plan) was completed, the former Response Working Group moved to a new focus of developing mitigations in response to *Bsal* detection and expediting policies for permitting actions that may be necessary if *Bsal* is detected in North America, even if those actions are disruptive to wild populations and their habitats. Such actions include, but are not limited to, ground-disturbing activities that could occur with fencing of areas or water containment and chemical applications at field sites with *Bsal* detection. The need for this pro-active step was identified in part as the result of a scenario-building exercise led by TAC members from the US Geological Survey (Hopkins et al. 2018) when it was recognized that ground-disturbing activities to forestall *Bsal* transmission at known sites of first-emergence in North America could be federally funded and may require NEPA (National Environmental Protection Act) policy to be followed, and use of chemical applications at field sites may require Environmental Protection Agency Section-16 approval. Hence, a new focus of the former Response Working Group was influenced by TAC members involved in the scenario exercise, which included an interaction of multiple partners and working groups, such as members of the Surveillance & Monitoring and Response Working Groups. The name of the Response Working Groups was changed to Response & Control Working Group to reflect the new goals and priorities it was assuming. Additionally, the TAC concurred with the decision by the Surveillance & Monitoring Working Group to move to a new phase of United States national *Bsal* field site surveillance and monitoring with partners at colleges and universities once their initial goal, led by US Geological Survey partners, to analyze ~10,000 animals for *Bsal* across the United States had been completed. Lastly, a new Clean Trade Working Group was recently initiated after TAC members were invited to speak at an annual meeting of the herpetofaunal trade industry sponsored by PIJAC, which focused new attention on Framework Action 1 (Box 1). This working group is expected to expand efforts to address potential human-mediated transmission of *Bsal* into North America via trade markets.

Goal A.2: Develop and strengthen lines of communication between the *Bsal* TAC and national leaders to address risk and response to *Bsal* emergence in North America.

Rank: Medium

Rationale: Development of a network of relevant partners to address concerns for *Bsal* in North America includes establishment of communication networks to higher-level national leaders with jurisdiction over the natural heritage of species and biodiversity in Canada, Mexico, the United States, and the First Nations and Indigenous peoples of North America.

Management Relevance: An Executive Oversight Group (Fig. 1) is envisioned to be created at a higher level than the TAC as a mechanism to more formally communicate with diverse natural resource managers or wildlife health leaders working at higher organizational levels of the government, especially as new *Bsal* information with high relevancy for nations becomes evident. These higher-level managers or leaders potentially include national-scale personnel, such as staff in the US Departments of Interior and Agriculture; the Association of Fish and Wildlife Agencies (AFWA), which includes federal, provincial and state leaders; the Canadian Wildlife Service (CWS), the Mexican Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), and PIJAC. The Medium ranking of this goal reflects the complexity of authorities that need to align to facilitate agreement to convene an Executive Oversight Group.

Financial Needs: In-kind support from member agencies and institutions for personnel time and travel.

Priority A.2.1: Work toward development of an Executive Oversight Group for communication to higher levels of natural resource management in North America.

Priority A.2.2: Maintain regular communication with national liaisons about *Bsal* Task Force or information developments.

Priority A.2.3: In particular, communicate with herpetofaunal, wildlife, epidemiological, or natural resource specialists in Mexico and nations of the Caribbean to inform them of *Bsal* Task Force or information developments that may be relevant to management of their natural heritage of amphibian species.

Background: The initiation of a *Bsal* Task Force Executive Oversight Group (EOG) was proposed to national leaders at the North American Wildlife and Natural Resources Conference in March 2016. Discussion there identified the need for such an oversight body to extend beyond *Bsal* and include other non-agricultural wildlife diseases with existing analogous task forces, such as white-nose syndrome in bats, as well as wildlife diseases without formalized task forces, such as sea star wasting disease. Although an EOG has not yet been formally convened to address multiple wildlife diseases, an EOG for non-agricultural wildlife diseases has been the topic of continued discussion and communications across groups and with leaders across jurisdictions and authorities since 2016. This topic also relates to a recognized gap in laws for wildlife health in the Canada, Mexico, and the United States. Although the US Animal Health Protection Act (7 USC § 109) covers agricultural wildlife health, there is no companion legislation for non-agricultural wildlife. Similarly, in Canada, the Health of Animals Act is targeted toward agricultural animal health, so the Wild Animal and Plant Protection and Regulation of International and Interprovincial Trade Act (WAPPRIITA) is used to control the spread of *Bsal* via controlling salamander imports instead. These are examples of issues that the EOG could address.

This aim of the *Bsal* Task Force TAC to engage an effective oversight group among relevant government agencies is an ongoing task. Currently, key national liaisons in different government sectors have been identified for communication, if relevant topics arise. The resulting structure of the *Bsal* Task Force (Fig. 1), envisioned to be a hierarchical structure with overarching counsel from the EOG, is informally occurring as wildlife health guidance continues to develop with key partners interfacing with the actions of the TAC and working groups. Priorities under this goal reflect ongoing activities in this arena.



Eastern Newt (*Notophthalmus viridescens*). © Alberto López.

B. Working Groups

Eight *Bsal* working groups have overarching goals per disciplinary area or thematic topic, which address one or more statements of the overarching Framework of Actions (Box 1). Within each of these goals are more detailed priorities of focused activities. The following sections detail the implementation plans of the objectives, goals, and priorities for the Response & Control, Diagnostics, Research, Decision Science, Surveillance & Management, Data Management, Outreach & Communication, and Clean Trade Working Groups.

Working group membership is open and inclusive, but the groups were initially founded with persons involved with disease research, natural resource management in state or provincial/territorial agencies and other government agencies, environmental or conservation groups, non-governmental organizations (NGOs), and the pet industry. Each working group has one to three leads, who help to coordinate personnel, manage the workload, and participate in the *Bsal* Technical Advisory Committee (TAC).



Three-lined Salamander (*Eurycea guttolineata*). © Alberto López.

1. Response & Control Working Group

Objective: To provide guidance for the rapid response (including, but not limited to, eradication, containment, or other management and control responses) should *Bsal* be detected in North America.

Working Group Lead: Laura Sprague (US Fish and Wildlife Service, ID, USA)

Past Working Group Lead: Priya Nanjappa (formerly of Association of Fish and Wildlife Agencies, Partners in Amphibian and Reptile Conservation, Washington, DC)

Background: Natural resource managers are often faced with making rapid decisions. The process can be quite overwhelming and confusing when dealing with multiple factors, like an emerging pathogen, species with conservation status of concern, and differing state or provincial/territorial and federal jurisdictions, regulations, policy, and permitting. The *Bsal* Response & Control Working Group aims to bridge the gap between identifying and implementing scientifically-sound mitigation actions in response to a confirmed *Bsal* detection in North America by proactively designing guidelines, identifying permitting steps, and facilitating the process of navigating the requirements for state or provincial/territorial and federal policy. Simply put, the purpose of the group is to facilitate efficient and rapid response to *Bsal* invasion.

In 2015, an initial Response Working Group focused on development of a *Bsal* Rapid Response Plan Template, addressing implementation Framework Action 2 (Box 1). After comprehensive review by federal, state, provincial, and other potential users of the Response Plan, this task has been completed, and the final product is included as Appendix 4 of the *Bsal* Strategic Plan (see salamanderfungus.org). The contents of the Rapid Response Plan are meant to be customized by any agency or institution with management jurisdiction over wild or captive salamanders so that the plan may serve as a template for actions required in case of suspected or confirmed *Bsal* detection.

The Rapid Response Plan Template is provided as an outline and guidance for local rapid response actions that could be triggered upon initial or subsequent detections of *Bsal*, in either

wild or captive populations. The scenarios involve different levels of diagnostic information for sick or dead animals. In other words, all recommended actions occur after the laboratory has made its determinations based on the *Bsal* case definition (White et al. 2016). Proactive actions to forestall *Bsal* emergence are not considered in this Rapid Response Plan Template but are being considered by the Decision Science Working Group, which is developing guidelines for implementing management actions before an introduction or outbreak is suspected or confirmed. The Rapid Response Plan Template provides considerations for in situ containment (i.e., in the existing location of the population) as well as establishment of ex situ populations (i.e., outside of the natural location, such as in a captive assurance colony). Rapid containment and response measures may prevent broad impacts of the infection. The USGS Amphibian Research and Monitoring Initiative (ARMI) is also working to assist entities in making decisions regarding wildlife disease management, including the customization of this template. Contact the ARMI Decision Science Lead, Dr. Evan Grant (ehgrant@usgs.gov), for assistance. The Rapid Response Plan is considered a living document that will be updated as more information becomes available. Updates will be posted on relevant websites (e.g., salamanderfungus.org).

After completion of the Rapid Response Plan Template (Appendix 4) and development of scenario-building exercises (Hopkins et al. 2018, Canessa et al. 2020), it became apparent that several aspects of responses to *Bsal* detection in North America warranted further development. These are tasks included in current priorities listed below.

***Bsal* Mitigation:** In 2018, the newly reconfigured Response & Control Working Group was formed to continue and expand the work described above. Specifically, the Response & Control Working Group aims to facilitate an efficient and effective response, by development of *Bsal* control mitigations, if *Bsal* were to be detected at a field or captive site in North America. This effort is part of Framework Actions 6 and 7 (Box 1), which also intersect the aims of other working groups, such as the Research and Decision Science Working Groups.

Mitigation strategies can target the host or environment. We can use what we have learned from *Bd* as a foundation for developing and understanding potential disease mitigation and treatment strategies and also take advantage of novel directions as new, innovative ideas are discovered through research. Host-directed strategies are mitigation tools aiming to foster disease resistance or tolerance, such as skin probiotics (Bletz et al. 2013; Harris et al. 2009a,b), vaccinations (McMahon et al. 2014; La Patra et al. 2015), and antifungal medications (Hudson et al. 2016; Hardy et al. 2015; Bosch et al. 2015). Environment-directed strategies include micropredator manipulations (Schmeller et al. 2014; Buck et al. 2011), salt augmentations (Stockwell et al. 2015a,b), environmental probiotics (Muletz et al. 2012), habitat alterations (e.g., fencing to reduce animal movements and human encroachment, water diversions to preempt *Bsal* transmission with water flow), and removal of infected hosts. These strategies have potential for mitigating *Bsal*'s impact on North American salamander biodiversity.

To implement *Bsal* management actions on the ground, government agencies may be required to follow national and/or state/provincial/territorial policies related to the potential environmental impacts resulting from such actions. For example, during scenario exercises of potential *Bsal* outbreaks in the United States (e.g., Hopkins et al. 2018), rapid responses were identified to be potentially slowed by lack of permits for United States federal or state authorities to assist in field responses including ground-disturbing activities, disturbance to species with conservation status of concern, and use of chemical applications to address the *Bsal* fungus viability. The Response & Control Working Group activities currently focus on understanding

the permits and approvals that may be needed for various *Bsal* actions in field or captive settings and expediting rapid permit processes. An effort is underway to gain a better understanding of the complex network of permits and procedures in the United States and the processes that may expedite those approvals. Similar initiatives in Canada and Mexico are anticipated. Existing policies and procedures for the United States federal and state lands are described below.

United States Federal Lands: United States federal agencies are required to follow the policies of the National Environmental Policy Act (NEPA) of 1970. The NEPA process or “Environmental Impact Assessment process” applies when a federal agency has discretion to choose among one or more alternative means of accomplishing a particular goal. It requires agencies to determine if their proposed actions have significant environmental effects to land and water, protected wildlife and plants, historic properties, cultural resources, and other interests as well as to consider the environmental and related social and economic effects of their proposed actions. NEPA’s procedural requirements apply to a federal agency’s decisions for a variety of actions, including, but not limited to, permanent or temporary construction projects, limiting public access to public lands, using chemical or biological treatments, and permitting of private actions.

In the United States, private and state entities will often become involved in the NEPA process when applying for permits if they will be using public land access or public waters in their actions. The NEPA process is generally a long, drawn-out process that can be difficult to navigate if you are not familiar with it and can take years to accomplish, but the process must be completed before federal management decisions are made.

The Council on Environmental Quality (CEQ) oversees the NEPA process with the help of the Environmental Protection Agency (EPA), which issues permits for chemical and biologic use based on the Clean Water Act and Clean Air Act.

Once a proposed action has been developed, an agency can pursue one of two paths:

1. Environmental Assessment (EA), which determines the significance of the action’s effects and finds alternative measures.
2. Environmental Impact Statement (EIS), which must be prepared if an action significantly affects the quality of the human environment.

If an action may occur more than once, or it occurs routinely, and will not have a significant impact on the human environment (either positive or negative), the agency may seek a categorical exclusion (CE) from CEQ that precludes the need to prepare an EA or EIS for future actions, but the process for obtaining approval from CEQ for a CE is lengthy and complex. The need must be carefully justified, and CEs are rarely granted. However, on rare occasions, CEQ may exempt an action from NEPA under the following circumstances:

1. If the agency needs to take an action in response to an emergency, and the action would typically require preparation of an EIS, but there is insufficient time to follow the regular NEPA process, then the agency can work with CEQ to develop alternative arrangements for compliance with NEPA (40 CFR § 1506.11) and proceed immediately to mitigate harm to life, property, or important resources.
2. The NEPA analyses and document may involve classified information. If the entire action is classified, the agency will still comply with the analytical requirements of NEPA, but the information will not be released for public review. If only a portion of the

information is classified, the agency will organize the classified material so that the unclassified portions can be made available for review (40 CFR § 1507.3(c))

United States State Lands: There are currently 16 states with Environmental Quality Acts that require state and local agencies to perform EISs or at least Environmental Reviews (ER) before performing actions and applying for permits. Please see Appendix 3 for a list of states with Environmental Quality Acts, the specific act to which they are bound, and the governing body of the act.

The Response & Control Working Group works in close association with the TAC, other *Bsal* working groups (e.g., Decision Science, Surveillance & Monitoring, and Clean Trade Working Groups), and partners. In addition, there is continued dialogue with the Research Working Group, Diagnostics Working Group, Outreach & Communication Working Group, Partners in Amphibian and Reptile Conservation (PARC), and the US Geological Survey Research and Monitoring Initiative. For example, the Decision Science Working Group helps biologists decide upon a course of action given the likelihood of success, the Research Working Group focuses on testing possible disease management options, and the Response & Control Working Group assists biologists with implementing management strategies.

Goal B.1.1: Review and update the Rapid Response Plan as new information becomes available.

Rank: High

Rationale: As knowledge accrues and response plans are trialed in workshop exercises or in real field or captive situations abroad or in North America, new information or lessons learned may be applied to adapt and improve the Rapid Response Plan.

Management Relevance: A variety of agencies, institutions, and authorities, as well as the general public, may be stakeholders in a *Bsal* response. An efficient, proactively created response plan can aid rapid action if *Bsal* were to be detected. Adapting current plans as new information becomes available elevates plan efficacy and can streamline processes and reduce uncertainty among management partners.

Financial Needs: In-kind support from member agencies and institutions for personnel time and travel.

Priority B.1.1.1: Stay current with new information that may be used during response actions if *Bsal* were to be detected in North America, including decision science systems, new research on *Bsal* mitigations, results of *Bsal* responses in Europe, biosecurity advances, and surveillance results.

Priority B.1.1.2: Interact with other relevant *Bsal* working groups to stay abreast of developing scientific or management breakthroughs that may affect *Bsal* response guidance.

Priority B.1.2.3: In the event of a *Bsal* detection in North America, offer assistance for the context-specific customization of the Rapid Response Plan using the template developed by the Response & Control Working Group.

Goal B.1.2: Facilitate and improve a natural resource agency’s ability to take proactive and reactive actions to prevent occurrence and transmission of *Bsal* in North America.

Rank: High

Rationale: Should *Bsal* invade North America, it is imperative to not only have a selection of effective mitigation options to counter the threat but also understand the steps needed to implement such actions.

Management Relevance: Proactive management and efficient response to outbreaks by natural resource agencies can be hindered by lengthy approval processes and lack of clarity surrounding the necessary steps. Our actions will offer guidance and tools to biologists, enabling them to efficiently implement strategies on the ground and, ultimately, fostering persistence of our native salamander diversity.

Financial Needs: In-kind support from member agencies and institutions for personnel time and travel.

Priority B.1.2.1: Define a list of proactive and reactive actions and tools available that can be taken by managers to prevent the introduction and spread of *Bsal*.

Priority B.1.2.2: Define and outline justifications for management actions, including effectiveness and possible (or lack of) environmental impacts relevant for applying for a US Department of Interior’s categorical exclusion (Cat Ex) approval.

Priority B.1.2.3: For each jurisdiction in North America, identify permits that may be needed for effective *Bsal* mitigation in response to *Bsal* detection at a field or captive site.

Priority B.1.2.4: Work with relevant government agencies that have regulatory oversight for actions with potential environmental impacts, under different site contexts, in order to develop an expedited plan for a rapid mitigation of *Bsal* occurrence and transmission.

Priority B.1.2.5: Work with relevant government agencies that have oversight for procedures to work with species of conservation concern at sites with *Bsal* detections, including their capture, *Bsal* testing, quarantine in captive settings, treatment, relocation, or euthanization.

Priority B.1.2.6: Develop “blanket documents” for exemption or permitting requests, as feasible per jurisdiction and context.

Priority B.1.2.7: Identify a list of contacts for rapid submission to relevant permitting agencies and develop a communication chain for expediting processes.

Priority B.1.2.8: Explore mechanisms to set up an emergency response fund and determine how to disperse such funds.

Goal B.1.3: Provide information and build understanding of *Bsal*, the *Bsal* Task Force, the Strategic Plan, and available management/mitigation options for federal agencies at the national and regional levels.

Rank: High

Rationale: Local and regional management will likely be the first to know of any potential *Bsal* detection and, to be proactive, should be kept well informed; keeping all levels of management informed will help to expedite any processes.

Management Relevance: Local, regional, and national managers can only effectively respond if they are provided with the needed information and understand the possible actions and steps needed to implement actions.

Financial Needs: In-kind support from member agencies and institutions for personnel time and travel. External funding resources may be needed for hard-copy brochure production.

Priority B.1.3.1: Develop briefing materials about *Bsal*, the *Bsal* Task Force and Strategic Plan, and available *Bsal* management tools (in collaboration with TAC and the Outreach & Communication Working Group).

Priority B.1.3.2: Develop a preliminary list of key national (in collaboration with the TAC) and regional (in collaboration with the national Disease Task Team of Partners in Amphibian and Reptile Conservation, as they have this list for their Herpetofaunal Disease Alert System) wildlife health and natural resource contacts for briefing material distribution.

Priority B.1.3.3: Devise a plan for briefing material distribution at national and regional scales.

Priority B.1.3.4: Distribute a *Bsal* informational brochure/white paper to local field offices of federal, state, tribal, and local agencies that may have vested interest in the detection and mitigation of *Bsal*.

Goal B.1.4: Brief and offer training to natural resource agencies (local to regional) about the North American *Bsal* Task Force and available management/mitigation options.

Rank: High

Rationale: Local and regional management will be the first to know of any potential *Bsal* detection and, to be proactive, should be kept well informed. Keeping all levels of management informed will help to expedite any processes.

Management Relevance: Local, regional, and national managers can only effectively respond if they are provided with the needed information and understand the possible actions and steps needed to implement actions.

Financial Needs: In-kind support from member agencies and institutions for personnel time, travel, and printing of training materials. Grants may be needed to cover costs of in-person, on-site standardized training across North America.

Priority B.1.4.1: Develop training materials for *Bsal* mitigation actions (in collaboration with the Outreach & Communication Working Group).

Priority B.1.4.2: Conduct a mock training session to assess efficacy of the pilot approach developed for the roll-out of management/mitigation options. Revise procedures as warranted.

Priority B.1.4.3: Provide training workshops, which could be done in-person or remotely, targeting local, regional, and national natural resource management groups (may vary by region, state/province/territory, or country).



Fire Salamander (*Salamandra salamandra*) infected with *Bsal*, as evidenced by the dark, circular lesions across its body. © Frank Pasmans.

2. Diagnostics Working Group

Objective: To assist with the promotion of consistent standards among the wildlife health community for detecting *Bsal* and diagnosing *Bsal* chytridiomycosis; to serve as a forum for exchanging ideas, working out challenges, and providing consultation and expert advice concerning *Bsal* detection and chytridiomycosis diagnosis.

Working Group Lead: Jacob Kerby (University of South Dakota, Vermillion, SD, USA)

Past Working Group Lead: María J. Forzán (College of Veterinary Medicine, Long Island University, NY, USA)

Background: Effective detection of novel disease-causing pathogens, such as *Bsal*, relies both on gross and microscopic (histopathologic) examination of lesions in affected animals and on the detection and correct identification of the pathogen through histochemical and molecular methods. Molecular detection of pathogens is a rapidly developing discipline largely reliant on technological advances in analyzing organismal DNA and RNA. Mortality due to *Bsal* was first described by Martel et al. (2013), who also provided a morphological description of the pathogen and the histopathologic lesions it caused and developed a polymerase chain reaction (PCR) assay specific to the 5.8S rRNA gene of *Bsal* that could be run on skin samples. As *Bsal* is closely related to *Batrachochytrium dendrobatidis* (*Bd*), and since bi-pathogen infections are possible, Blooi et al. (2013) developed a duplex real-time PCR assay to detect and differentiate both pathogens. Further advancing the development of reliable standardized diagnostic procedures for *Bsal* is an overarching goal for the working group.

The *Bsal* Diagnostics Working Group was convened as a partnership among diagnosticians and researchers interested in further development of effective diagnostics tools for *Bsal*, addressing Framework Action 3 (Box 1). The Diagnostics Working Group is composed of professionals with expertise in the application and interpretation of an array of diagnostic tools, with members working in academia, diagnostic laboratories, and government agencies

throughout North America and involved in detection and reporting of amphibian diseases, including *Bsal*.

Since the working group's assembly in 2015, collaborations between members of the group and others have achieved several initial goals. First, the *Bsal* case definition (White et al. 2016) was published to establish criteria to promote standardized communication of diagnostic results for diagnosis of *Bsal*-caused disease, i.e., *Bsal* chytridiomycosis. The case definition describes the clinical and histopathological presentation of *Bsal* chytridiomycosis and references Martel et al. (2013) and Blooi et al. (2013) for molecular analyses by PCR. Since then, additional recommendations on diagnosing *Bsal* chytridiomycosis have been produced (see Thomas et al. 2018). A second achievement was the completion of a pilot multiple-laboratory round-robin proficiency test for *Bsal* detection by PCR in 2016 and the development of a methodology and logistics plan for a full round-robin, both with funding from Environment and Climate Change Canada. Third, an in situ hybridization protocol to detect *Bd* and *Bsal* cells in formalin-fixed paraffin-embedded tissues was developed (Ossiboff et al. 2019)—definitive differentiation of *Bd* and *Bsal* in tissue sections of affected amphibians is impossible based on fungal morphology and routine histologic stains alone. As the case definitions for *Bsal* and *Bd* chytridiomycosis require both histologic and molecular evidence of infection, this new test to simultaneously screen for and differentiate the two fungal pathogens in tissue sections is critical for accurate diagnosis. Ongoing work by the group is capitalizing upon the value of collaborations among diagnosticians and researchers with different expertise. Goals and priority actions per goal are described further in the *Bsal* Implementation Plan (Appendix 5), and annual reports summarize the working group's activities (salamanderfungus.org).

The Diagnostics Working Group has close interactions with the Research Working Group and the Surveillance & Monitoring Working Group and has intermittent interactions with the Response & Control, Data Management, and Outreach & Communication Working Groups.

Goal B.2.1: Establish a long-term program for inter-laboratory quality control and evaluation of protocols for the detection of wildlife pathogens, particularly *Bd* and *Bsal*.

Rank: Urgent

Rationale: Research and diagnostic laboratories throughout the world run PCR tests to detect wildlife pathogens. Standardization of methodologies is difficult, and it is even more difficult for small research laboratories to acquire a certification granted by organizations such as the American Association of Veterinary Laboratory Diagnosticians or ISO (International Organization for Standardization) committees. An option should exist to provide an accessible method for quality control/quality assurance that will allow participating laboratories to confidentially evaluate the quality of their own results. Based on a successful pilot round-robin proficiency test, a formal program to provide annual quality testing to all volunteer laboratories can be established. The program would provide blind samples to participating laboratories, collate results, and provide feedback to all participants. Two things are crucial to the success of such a program: 1) providing the blind samples free of charge so laboratories with limited budgets are not excluded and 2) maintaining the origin of results confidential so all participants can see where their results compare to the group, but no one is able to match a set of results to a specific laboratory.

Management Relevance: Establishing a free and accessible quality control source for laboratories testing for the presence of *Bsal* enhances the overall accuracy of results; more reliable results translate into decreased uncertainty and increase the confidence natural resource managers can place on those results. Reliable results are key when managers are tasked with making decisions for rapid-response actions, should *Bsal* be detected in North America.

Financial Needs: Cost estimate: 60,000 USD; partial funding provided by Environment and Climate Change Canada, who covered the development of a methodology and logistics plan.

Priority B.2.1.1: Determine a laboratory that can produce annual sets of samples containing pre-determined concentrations of inactivated *Bd* and *Bsal* zoospores in solution.

Priority B.2.1.2: Identify a group of laboratories willing to participate in testing blind samples and committed to reporting their results within a pre-determined period of time and following an established format that includes a minimum of methodological information.

Priority B.2.1.3: Develop a web-based platform for the collection of results and feedback to participating laboratories as well as a deposit of information regarding recommended methodologies.

Priority B.2.1.4: Provide a set of blind samples that includes blanks and one or both amphibian chytrid fungi (*Bsal* and *Bd*).

Priority B.2.1.5: Collate reports from participating laboratories and provide feedback to all participants. Produce a list of participating laboratories to share with agencies and other institutions interested in submitting samples for testing or collaborating in testing projects.

Goal B.2.2: Develop standardized and reproducible methods that will allow comparison across studies, with reliable detection of *Bd* and *Bsal* and reliable estimation of infection load once either or both pathogens are detected.

Rank: Urgent

Rationale: Numerous laboratories are already running *Bsal* PCR tests, both in native and exotic amphibians. Testing various protocols and establishing one that is most effective and that can fit the majority of technical settings would empower laboratories and provide an easier way to compare results among them. A common request from diagnosticians and researchers is the establishing of a set of recommended standards.

Management Relevance: Development of efficient and standardized diagnostic procedures allows comparison of results among contexts, such as different sites. This approach provides a foundation for geographic or taxonomic comparisons of *Bsal* detection and reduces uncertainty, allowing natural resource managers to more confidently implement rapid response actions should *Bsal* be detected in North America.

Financial Needs: 135,000 USD; unfunded at present.

Priority B.2.2.1: Establish a short list of protocols that are most likely to be used across agencies and institutions.

Priority B.2.2.2: Identify a group of laboratories willing to participate in testing blind samples following specific protocols—a subset of the round-robin participants would be best.

Priority B.2.2.3: Provide detailed instructions on the protocols to be used for the tests run by participating laboratories.

Priority B.2.2.4: Define common metrics that laboratories should report to determine chytrid detection and quantification and the variability of chytrid detection when using molecular tools.

Priority B.2.2.5: Provide a set of blind samples that includes blanks and one or both amphibian chytrid fungi (*Bsal* and *Bd*).

Priority B.2.2.6: Collate reports from participating laboratories, establish the protocol(s) that yielded most consistent results, and determine intra-laboratory repeatability and inter-laboratory reproducibility.

Priority B.2.2.7: Establish a mechanism to provide laboratories with the standard(s) deemed most appropriate based on the round-robin results.



Flatwoods Salamander (*Ambystoma cingulatum*). © Mark Mandica.

3. Research Working Group

Objective: To facilitate communication and collaboration among scientists studying *Bsal* in North America and to ensure that high-quality research on *Bsal* is produced rapidly.

Working Group Lead: Molly Bletz (University of Massachusetts, MA, USA) and Jonah Piovia Scott (Washington State University, WA, USA)

Past Working Group Leads: Doug Woodhams (University of Massachusetts, MA, USA); Matt Gray (University of Tennessee, TN, USA); Reid Harris (formerly of James Madison University and Amphibian Survival Alliance, VA, USA)

Background: The breadth of *Bsal* research needs span basic, applied, and theoretical science disciplines; advances in all three arenas are needed to build foundational knowledge essential for responding to *Bsal* emergence. Scientific studies across these arenas broadly address Framework Actions 4 through 6 (Box 1). To achieve a broad scope of work, the *Bsal* Research Working Group is a collaboration of scientists with a diversity of expertise from multiple disciplines, including molecular and cellular biology, immunology, ecology, mathematics, pathology, and social sciences. The group strives for inclusion and productive collaboration and to maintain or expand its participants to effectively address open research questions critical to our ability to respond to and manage *Bsal*. The working group is currently composed of >30 members, representing >20 organizations.

The Research Working Group maintains a list of research needs based on recent publications, our current state of knowledge, and key knowledge gaps. The working group ranks research

needs on the list as Urgent, High, or Medium priority. Within each of these categories, research needs are considered to have equal importance. Each year, the list is updated as more information becomes available and ranks change. Ranks are associated with the thematic goals for the Research Working Group, listed below. The research goals identified below represent a comprehensive approach to advancing the understanding of *Bsal*'s potential impact on amphibian host communities and effective response and management approaches should *Bsal* be introduced into North America. The goals are broken down into priority research studies (i.e., action items); achievements are listed in annual reports (salamanderfungus.org).

The Research Working Group interacts with several other working groups (Fig. 1), including key ties to the Decision Science, Data Management, and Diagnostics Working Groups and additional interactions on specific topics with the Response & Control, Outreach & Communication, and Clean Trade Working Groups. In particular, research can inform management decisions and can evaluate effectiveness of intervention strategies collectively identified in collaboration with the Decision Science Working Group and the Response & Control Working Group. The Research Working Group endeavors to reduce uncertainties that impede proactive and responsive strategies. The Decision Science Working Group will consider multiple objectives, preferences and values of individual decision-makers, risk profiles, current research frontiers, and uncertainty. For example, identifying possible management interventions for infected habitats (Goals B.3.4, B.3.7) can be done in a decision analysis framework to identify the optimal strategy, given species-specific susceptibility (Goal B.3.3), and calculate the importance of reducing remaining uncertainties to improve decisions. Hence, it is essential that the Research Working Group interacts with the other working groups to produce research with applied implications.

Goal B.3.1: Understand the role of human behavior and the pet trade in the spread and spillover of *Bsal*.

Rank: Urgent.

Rationale: Past experiences with emerging infectious diseases in wildlife populations have shown that pre-emptive and precautionary actions are essential to the success of containing and reducing the spread of novel pathogens (Langwig et al. 2012). Thus, the investment in *Bsal* research will provide an excellent case example of the usefulness of science-based preparedness in responding to novel pathogen introductions in the wild and is specifically relevant to *Bsal* transmission routes in trade markets.

One of the most likely routes of entry for *Bsal* into North America is unclean international trade of amphibians (Gray et al. 2015). Currently, animal health certificates for internationally traded wildlife are not required for most nations, including the United States. Although the US Fish and Wildlife Service rule banning the trade of some salamander genera may have reduced the likelihood of infected animals entering the United States via trade (Grant et al. 2017), the ban does not include many taxa (e.g., frogs) that are known suitable hosts (based on recent studies or unpublished data). Yuan et al. (2018) estimated that up to 66,000 salamanders infected with *Bsal* could have entered the United States in the past 10 years, and their estimates did not include frogs, which constitute 94% of imported amphibians. Indeed, *Bsal* has been documented in trade in Europe (Nguyen et al. 2017, Fitzpatrick et al. 2018, Sabino-Pinto et al. 2018), and trade is hypothesized as the route of entry from Asia, where *Bsal* is endemic, to the European continent (Martel et al. 2014, Nguyen et al. 2017). Information on the occurrence of *Bsal* in the North

American amphibian pet trade is needed. Klocke et al. (2017) performed preliminary surveillance for *Bsal* in the United States pet trade and did not detect it. However, their small sample size may have prevented detection of the pathogen at low prevalence (Yuan et al. 2018). Limited *Bsal* surveillance studies in the pet trade have been published for Canada and Mexico (Govindarajulu et al. 2017). In the case of Mexico, a formal petition has been made to the corresponding federal agency (Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria [SENASICA]) so that amphibian imports will be screened for *Bsal*; however, the petition is still under evaluation. Additional information about the potential for commonly traded amphibian species to carry *Bsal* is also needed and will help guide surveillance efforts.

In addition to knowing whether *Bsal* exists in North America and its prevalence in the continent's pet trade, we need to understand human dimensions, e.g., the likelihood of consumers releasing unwanted pet amphibians or disposing of their aquarium contents in the environment. This likelihood may differ between hobbyist and specialist amphibian consumer groups. If *Bsal* is detected in the pet trade or the wild, it is important to know the willingness of consumers to participate in programs designed to modify public behavior in a way that will limit pathogen spread, such as providing unwanted pet amphibian amnesty programs and using disinfectants known to kill *Bsal* zoospores at home (aquaria) or in the field (recreational gear).

The studies described below will use a combination of non-lethal testing of amphibians in the pet trade for *Bsal* infection, methods to understand carrier capacity of highly traded amphibians, and human dimension surveys to characterize public awareness, perceptions, and behaviors associated with *Bsal*.

Management Relevance: The North American Model of Wildlife Management relies on evidence-based decision making. For an effective *Bsal* management response, science-based support for context-specific pathogen occurrence, host disease susceptibility, and efficacy of management or treatment alternatives is imperative to reduce uncertainty in manager or policy-maker decision making. Surveillance for *Bsal* in the pet trade is essential to knowing whether this foreign pathogen is in North America. Estimates of prevalence can be combined with shipping and distributor information to identify areas where spillover is most likely to occur, which can direct field activities. Understanding human behavior is also essential to assessing risk of human-mediated spillover or translocation of *Bsal* among sites and estimating public perceptions of future programs or regulations designed to thwart *Bsal* emergence.

Financial Needs: 30,000 USD per state/province/territory/port of entry; 15,000 USD per species; partial funding received for species research. A study by Klocke et al. (2017) addressed Priority B.3.1.1.

Priority B.3.1.1: Estimate the occurrence and prevalence of *Bsal* in the North American pet trade through non-lethal surveillance of amphibians at ports of entry, wholesale distributors, and retail stores.

Priority B.3.1.2: Estimate the susceptibility of potential *Bsal* hosts (salamanders and frogs) in the pet trade (e.g., species commonly imported from Southeast Asia).

Priority B.3.1.3: Characterize human behaviors for amphibian hobbyist and specialist groups to estimate the likelihood of *Bsal* spillover from consumers to wild populations and the acceptance of public outreach strategies designed to limit the anthropogenic spread of *Bsal*.

Goal B.3.2: Identify critical transmission pathways and conditions under which *Bsal* is likely to emerge in amphibian host populations in North America (e.g., compartmental disease models).

Rank: Urgent.

Rationale: Identifying the importance of transmission pathways under varying conditions is fundamental to characterizing the epidemiology of host–pathogen systems and developing effective disease intervention strategies (Tien and Earn 2010, Langwig et al. 2012). Environmental transmission of *Bsal* can occur through water or soil, and it depends on various factors, such as host shedding rates of the pathogen and pathogen persistence outside of the host (Nelson et al. 2009, Briggs et al. 2010, Stegen et al. 2017). Transmission can also occur through direct contact between infected and uninfected individuals. The probability of transmission can change as disease progresses in the host (McCallum et al. 2001, Peace et al. 2019). We recommend development of *Bsal* epidemiology models for widely distributed, abundant host species in North America that are known to be susceptible to *Bsal* (e.g., Eastern Newt [*Notophthalmus viridescens*], Rough-skinned Newt [*Taricha granulosa*]), given their potential to maintain, amplify, and spread *Bsal*. The action items below outline the parameterization of models that can be used to identify key transmission pathways and conditions under which *Bsal* is likely to emerge. The proposed work involves a combination of controlled experiments and mathematical modeling following models developed for *Bd* (Briggs et al. 2010), *Ranavirus* spp. (Peace et al. 2019), and *Bsal* (Schmidt et al. 2017).

Management Relevance: These predictive models can provide insight into transmission pathways, environmental conditions, and population characteristics that can be manipulated to reduce the impacts and persistence of *Bsal* at a site. For example, if direct contact between individuals is a key transmission pathway, intervention strategies that reduce contacts should be used, such as altering habitat structure or reducing animal density. If environmental transmission is a key pathway, strategies that change conditions to reduce zoospore persistence should be implemented. If non-amphibian hosts can contribute to the persistence of *Bsal* in the environment, strategies can be directed at managing these groups.

Financial Needs: 2.1 million USD; partial funding by the United States’ National Science Foundation for Priorities B.3.2.1–B.3.2.5. A study by Longo et al. (2019) addressed Priority 3.2.6.

Priority B.3.2.1: Estimate latency period of infection and recovery rate for pre- and post-metamorphic amphibian hosts at biologically relevant temperatures.

Priority B.3.2.2: Estimate daily shedding and encystment rate of *Bsal* zoospores and the infectious dose (ID)₅₀ for pre- and post-metamorphic amphibian hosts at biologically relevant temperatures.

Priority B.3.2.3: Estimate daily contact rates of amphibian hosts at relevant temperatures and densities when exposed to different complexities of habitat structure.

Priority B.3.2.4: Estimate probability of *Bsal* transmission between infected and uninfected amphibian hosts (within and between species) at different post-exposure durations and temperatures.

Priority B.3.2.5: Estimate the duration of zoospore persistence in water and soil given differences in various environmental conditions (e.g., temperature, micropredators, soil moisture, water chemistry, and bacterial presence).

Priority B.3.2.6: Estimate the influence of co-infection with other pathogens (e.g., *Bd*, *Ranavirus* spp.) on the likelihood of *Bsal* transmission and development of chytridiomycosis.

Priority B.3.2.7: Determine the probability of transmission or translocation of *Bsal* by non-amphibian hosts (e.g., crayfish, waterfowl, humans) and understand their role as potential biological reservoirs.

Goal B.3.3: Produce more informed *Bsal* risk models for North America through improved, objective classification of species susceptibility and tolerance to *Bsal* infection (e.g., integral projection models).

Priority: Urgent

Rationale: The likelihood of pathogen invasion is commonly modeled using risk analyses, which can be dependent on environmental conditions, host species distribution and susceptibility, and population characteristics (Václavík et al. 2010, OIE and IUCN 2014). Preliminary *Bsal* risk models for North America based on environmental suitability indices for *Bsal* and salamander distributions suggest that the Southeast, Northeast, and Pacific Coast of the United States and south-central Mexico have high invasion potential (Yap et al. 2015, 2017; Richgels et al. 2016; Basanta et al. 2019). One limitation of these predictions is that little information was available for incorporating host susceptibility into the risk estimates. Evidence for species susceptibility is being rapidly expanded (Martel et al. 2014, Barnhart et al. 2020, Carter et al. 2020; unpubl. data). Since autumn 2015, the susceptibility of a number of North American amphibian species to *Bsal* has been estimated among several United States laboratories (Appendix 1). Integral projection models (IPMs) can be used to categorize species susceptibility, considering their tolerance to infection (Wilber et al. 2016). Susceptibility indices can be combined with host species distributions and environmental niche data for *Bsal* to more robustly predict risk of pathogen invasion geographically. Biologists can use risk assessments to target locations for disease response and management actions. IPMs can also be used to classify the potential role of species during disease outbreaks (Wilber et al. 2016), which could range from resistant to reservoir to amplification hosts (Paull et al. 2012). Knowing the potential contribution of host species to community-level transmission can help direct disease intervention strategies, which can differ depending on host susceptibility (Streicker et al. 2013). The proposed work involves a combination of dose-dependent experiments and mathematical modeling to objectively categorize and rank species susceptibility.

Management Relevance: Comprehensive assessment of species susceptibility to *Bsal* in North America will produce robust *Bsal* risk maps (similar to Yap et al. 2015, Richgels et al. 2016, Basanta et al. 2019) highlighting areas in which pathogen surveillance and disease response actions can be targeted. Additionally, IPMs can lead to objective rankings of species susceptibility and classifications of epidemiological roles (e.g., resistant, reservoir or amplification species), which provide insight into community-level impacts at sites. For example, communities dominated by carrier species (i.e., high *Bsal* tolerance) may experience

minimal disease occurrence but have high *Bsal* infection prevalence and be sites where the pathogen is maintained. In contrast, sites dominated by amplification species (i.e., low *Bsal* tolerance) may experience rapid *Bsal* transmission, disease progression, and population declines.

Financial Needs: 15,000 USD per species, Priority B.3.3.1, partially funded by the BAND Foundation; 300,000 USD each, Priority B.3.3.2 (partially funded by the Smith Conservation Fellowship and National Science Foundation) and Priority B.3.3.3 (partially funded by the National Science Foundation); 200,000 USD, Priority B.3.3.4, funded by US Fish and Wildlife Service.

Priority B.3.3.1: Estimate the susceptibility (i.e., tolerance) of North American amphibians to *Bsal* infection and chytridiomycosis using standardized, dose-dependent experiments (suggestions for targeted taxa can be provided by the lead of the Research Working Group).

Priority B.3.3.2: Estimate the impact of habitat characteristics (temperature, pH, salinity, zooplankton abundance, etc.) on *Bsal* infection risk.

Priority B.3.3.3: Develop integral projection models (IPMs) that predict tolerance using temporal estimates of *Bsal* infection load and host fitness metrics (e.g., survival, disease ranking based on microscopic and gross lesions).

Priority B.3.3.4: Use information developed in Priorities B.3.3.1–B.3.3.3 to map susceptibility indices on the geographic distributions of hosts and environmental suitability niches for *Bsal* to produce robust spatial predictions of *Bsal* risk in North America.

Goal B.3.4: Identify effective methods for managing *Bsal*-induced disease and clearing *Bsal* infections in captive and field settings.

Rank: Urgent

Rationale: Managing disease threats, like those posed by *Bsal*, are of the utmost importance for conservation. A proactive strategy for developing disease mitigation tools is imperative for having an effective rapid response if *Bsal* is introduced into North America (Grant et al. 2017). Priority for disease mitigation should focus on highly susceptible amphibian taxa as well as tolerant hosts that may act as *Bsal* reservoirs within the ecosystem. Mitigation strategies targeting the host, such as vaccination or probiotic bioaugmentation of the skin microbiota, or strategies targeting the environment, such as micropredator augmentation, are possible conservation frontiers for field-based mitigation (Bletz et al. 2013, Garner et al. 2016, Thomas et al. 2019). We can use what we have learned from *Bd* as a foundation for developing and understanding potential disease mitigation and treatment strategies and also take advantage of novel directions. Within the amphibian *Bd* studies, the addition of locally occurring protective bacteria to amphibian skin has effectively prevented *Bd*-associated chytridiomycosis in laboratory trials and a field trial (Harris et al. 2009a,b; Vredenburg et al. 2011). Additionally, early studies suggest that adaptive immunity can be induced by a vaccination strategy (McMahon et al. 2014). Nasal delivery of vaccines against bacterial and viral infectious diseases has shown promising results in Rainbow Trout (*Oncorhynchus mykiss*; La Patra et al. 2015) and may be an effective strategy for treating amphibian species. Furthermore, *Bd* infection risk has

been correlated with environmental micropredators, and certain microeukaryotes can greatly reduce infection probability and reduce zoospore persistence in experimental contexts (Schmeller et al. 2014). Therefore, manipulation of micropredator communities could serve as a feasible strategy to minimize *Bsal* infection risk. A recent review by Thomas et al. (2019) described possible strategies for mitigating *Bsal*, critical knowledge gaps, and future research directions.

Development of infection clearance strategies for traded amphibian species that can carry *Bsal* can allow trade to continue while minimizing the risk of *Bsal* introduction. Heat therapy and antifungal treatments have been found to be effective for European Fire Salamanders (*Salamandra salamandra*) (Bloom et al. 2015a,b). However, such treatments may not be suited for all amphibian species. Many species cannot tolerate elevated temperature and/or antifungal medications (e.g., itraconazole; Baitchman and Pessier 2013).

Management Relevance: Disease response is essential to thwarting pathogen outbreaks. Because amphibians have relatively low dispersal capability, host- and site-based management strategies can be effective, and their effectiveness has been demonstrated in some cases for *Bd* (Vredenburg et al. 2011, Bosch et al. 2015). Upon identification of effective strategies, natural resource agencies will be equipped with the best practices to prevent (proactive) or reduce (reactive) *Bsal* chytridiomycosis in amphibian habitats and populations.

Financial Needs: 900,000 USD total, Priorities B.3.4.1–B.3.4.6; 150,000 USD per strategy, partially funded by the David H. Smith Conservation Fellowship, Foundation for the Conservation of Salamanders, US Fish and Wildlife Service; 600,000 USD total, Priorities B.3.4.7–B.3.4.11, partially funded by the National Science Foundation and US Fish and Wildlife Service.

Priority B.3.4.1: Identify effective probiotic microbes and develop probiotic treatment methods to combat *Bsal*, including the exploration of host and environmental modes of treatment. Test non-target impacts of probiotics and examine potential for bacteremia through lesions.

Priority B.3.4.2: Identify *Bsal*-consuming aquatic micropredators from natural habitats and test micropredator augmentation strategies.

Priority B.3.4.3: Evaluate novel vaccination methods as a possible disease mitigation tool and test different modes of delivery (e.g., different life stages, nasal-associated lymphoid tissue vaccination, skin exposure, nanoparticle technology).

Priority B.3.4.4: Explore the use of *Bsal* removal methods (e.g., attractants or traps).

Priority B.3.4.5: Explore the genetic correlates of disease resistance and the possibility of selectively breeding hosts for *Bsal* resistance.

Priority B.3.4.6: Evaluate the potential use of disinfectants in the field to eradicate *Bsal* from a small area after a point source introduction (sensu Bosch et al. 2015).

Priority B.3.4.7: Determine minimal alterations to habitats that can promote disease risk reductions (e.g., increasing habitat temperature through shade reduction, altering pH or salinity, changing complexity of habitat structure to affect contact rates, dewatering habitats) or augment habitats with native anti-*Bsal* microbes.

Priority B.3.4.8: Determine the effectiveness of reducing host density or altering relative abundance of host species with different infection tolerances on the invasion potential of *Bsal*.

Priority B.3.4.9: Identify volatile organic compound (VOC)-producing, *Bsal*-inhibitory microbes and their inhibitory compounds.

Priority B.3.4.10: Test alternative antifungal compounds for use on a broad host taxonomic range and across life-history stages.

Priority B.3.4.11: Test the use of microbes and/or compounds to clear existing infections and minimize side effects.

Goal 5: Quantify innate and adaptive immune responses to *Bsal* across species and environmental conditions.

Rank: High

Rationale: Little is known about the immune defenses of salamanders against *Batrachochytrium* fungi. Preliminary research suggests that the Fire Salamander (*Salamandra salamandra*)—a European newt species in which exposure to a low dose of *Bsal* results in disease—has few effective immune defenses against *Bsal* infection (Martel et al. 2013, Van Rooij et al. 2015). Other salamander species appear to be more resistant to *Bsal* chytridiomycosis, and several anuran species can clear infection (Martel et al. 2014, Stegen et al. 2017). Despite initial findings with species susceptibility trends (Goal B.3.3), the role of amphibian immune defenses in mediating host response to *Bsal* infection remains largely unknown. Immunocompetence in amphibians can differ among life-history stages (i.e., age classes), among populations, and with changes in environmental conditions. In particular, amphibian immunity is influenced by temperature (Rollins-Smith 2017). Like other vertebrates, the immune system of amphibians includes innate and adaptive components. For skin pathogens like chytrid fungi, antimicrobial peptides produced in the skin can be an important first defense (Holden et al. 2015). Symbiotic microorganisms on amphibian skin can also contribute to immunity through direct competitive interactions or by producing antimicrobial byproducts (Woodhams et al. 2018). Adaptive immune responses to *Bsal* are unknown. Understanding the mechanisms of host disease resistance can lead to the development of intervention strategies focused on host immunity, such as use of vaccines and bioaugmentation techniques. Because *Bsal* creates necrotic skin ulcerations that can extend through the epidermis (Martel et al. 2013), possible probiotic treatments need to be evaluated to ensure they do not contribute to bacteremia and sepsis (Bletz et al. 2018).

Management Relevance: A mechanistic understanding of amphibian immune responses to *Bsal* will enable directed mitigation approaches. For example, determining how protective immunity can be established in salamanders may direct management toward vaccines or probiotic microbial therapy or other approaches to increase salamander resistance to chytridiomycosis. It also may be possible to alter habitat conditions to facilitate some host immune responses.

Financial Needs: 1.3 million USD, partial funding from the National Science Foundation, Eastern Newt focus.

Priority B.3.5.1: Determine whether amphibians are able to develop a lymphocyte-mediated immune response to *Bsal* and how this and other responses compare among species, populations, and life stages and across environmental conditions.

Priority B.3.5.2: Determine whether salamanders produce antimicrobial skin peptides or other antimicrobial compounds and if skin toxins used for defense (e.g., tetrodotoxin, TTX) influence antimicrobial product production.

Priority B.3.5.3: Determine whether amphibians or symbionts produce antifungal small molecule compounds.

Priority B.3.5.4: Determine how the skin microbiome (bacteria, fungi, viruses) interacts with immune responses and influences disease susceptibility. Also, determine if the skin microbiome can be manipulated and whether it varies with environmental conditions and host genetics.

Priority B.3.5.5: Establish hematological reference values and determine how these parameters reflect immunity to *Bsal* infection in amphibian hosts.

Priority B.3.5.6: Determine whether there is protective immunity that develops upon host clearance of *Bsal* and repeat exposure. Determine how protective immunity can best be established (e.g., vaccine, heat-clearing *Bsal*). Also, determine what immune responses are regulated by protective immunity (e.g., mucosal antibodies, skin defense compound expression, changes in microbiome).

Goal B.3.6: Identify the mechanisms of *Bsal* pathogenesis.

Rank: High

Rationale: The mechanisms by which *Bsal* becomes a lethal pathogen are unknown (Van Rooij et al. 2015). Grossly and anatomically, chytridiomycosis due to *Bsal* develops differently in a host than does *Bd*. *Bd* results in hyperkeratosis (i.e., skin thickening), whereas *Bsal* causes ulcerative, necrotic skin lesions that can extend through the epidermis. The mechanisms of pathogenesis for *Bd* are compromised osmoregulation across the skin that leads to electrolyte imbalance in the blood (especially Na^+ , K^+ , and Ca^{2+}), which affects epidermal electrolyte transport, leading to asystolic cardiac arrest (Voyles et al. 2009). The physiological mechanisms for *Bsal* pathogenesis may be similar to *Bd* (i.e., altered osmoregulation); however, electrolyte imbalance may be a consequence of skin destruction instead of hyperplasia. It is also possible that reduced cutaneous respiration could be a morbidity factor in *Bsal*-induced chytridiomycosis. In general, salamanders rely on cutaneous respiration more than frogs, especially species in the Plethodontidae (lungless salamander) family (Wells 2007). Bacteremia is another hypothesized mechanism of *Bsal* chytridiomycosis (Bletz et al. 2018).

The proposed work involves a combination of clinical and anatomical pathology to quantify structural and physiological changes in salamanders as *Bsal* chytridiomycosis progresses. Additional areas of exploration will include the molecular pathways required for initial interactions between *Bsal* zoospores and their hosts. In particular, understanding how the *Bsal* zoospore is attracted to a suitable host (e.g., chemotaxis) and adheres are important areas for research and represent possible opportunities for prevention or reduction of infection. Other areas of research focusing on *Bsal* biology that will provide important insight into pathogenesis

include understanding how *Bsal* infection spreads through host tissue and identifying molecular signatures specific to host infection.

Management Relevance: Understanding the pathology of *Bsal* will enhance our ability to predict susceptible species and provide the groundwork for making informed decisions about where and how to manage *Bsal* emergence.

Financial Needs: 1.2 million USD; partially funded by the National Science Foundation.

Priority B.3.6.1: Quantify the changes in plasma electrolyte concentrations in *Bsal*-infected salamanders.

Priority B.3.6.2: Identify whether bacterial invasion through the skin via *Bsal* lesions and sepsis are contributing factors to pathogenesis.

Priority B.3.6.3: Identify tissue tropism for *Bsal*-infected amphibians.

Priority B.3.6.4: Explore mechanisms of attraction to (chemotaxis) and physical binding of zoospores to hosts.

Priority B.3.6.5: Determine whether *Bsal* releases lymphotoxic or cytotoxic molecules.

Goal B.3.7: Establish effective methods for detecting *Bsal* infections.

Rank: Urgent

Rationale: Managing disease threats, like those posed by *Bsal*, are of the utmost importance for conservation. A first step is preventing entry of the pathogen into naïve regions like North America, and therefore, rapid and accurate detection of the pathogen is crucial. Recent histological advances have provided a novel tool for identifying coinfections using RNAScope (Ossiboff et al. 2019). This objective intersects directly with the Diagnostics Working Group.

Management Relevance: Detecting and tracking existing *Bsal* infections from captive-housed amphibians is critical in the pet trade and for captive management of critically endangered amphibians or amphibians used in research. Improved methods may enable more effective policy recommendations and make it easier to eliminate threats.

Financial Needs: 350,000 USD; unfunded at present.

Priority B.3.7.1: Develop new diagnostic tools and improve existing tools.

Goal B.3.8: Estimate the interactive effects of *Bsal* with natural and anthropogenic stressors.

Rank: Medium

Rationale: Laboratory estimations of the susceptibility of amphibian species to *Bsal* are a good starting point for developing landscape risk models for *Bsal* emergence. However, amphibians have complex life histories and unique physiologies that make them particularly sensitive to stressors. Indeed, amphibians are heavily dependent on water, making them particularly sensitive to altered hydroperiod, desiccation, and decreases in water quality. Examples of impaired water

quality include increased salinity, acidity, eutrophication, and pesticide contamination. In many cases, environmental stressors induce changes in host behavior and physiology that could potentially influence risk from *Bsal*. For example, changes in body condition or corticosterone (a hormone commonly elevated in response to stressors) can modulate immune function and possibly susceptibility to *Bd* (Tatiersky et al. 2015, Fonner et al. 2017). Similarly, physiological and behavioral responses to desiccation (e.g., changes in plasma osmolality, increased osmoregulatory behaviors) may influence infection dynamics and disease progression. These effects may be exacerbated or mitigated in more complex environments (e.g., mesocosms) by changes in community interactions and habitat quality.

Management Relevance: Understanding how environmental and community conditions modulate susceptibility to *Bsal* will help predict invasion risk. In addition, if stressors are identified (e.g., pesticides), management strategies can be implemented to reduce the effect of the stressor.

Financial Needs: 150,000 USD per stressor, Priority B.3.8.1; 300,000 USD Priority B.3.8.2.

Priority B.3.8.1: Conduct susceptibility trials that include common natural and anthropogenic stressors (e.g., hydration, salinity, pesticides) to determine if outcomes following *Bsal* exposure are altered.

Priority B.3.8.2: Conduct susceptibility trials in complex settings that include community features such as predation and trophic interactions and changing habitat quality.



Northern Gray-cheeked Salamander (*Plethodon montanus*). © Alberto López.

4. Decision Science Working Group

Objective: To support management decisions regarding *Bsal* through the facilitation of decision-making processes, identification and collation of information needed to make decisions, development of models to predict the outcomes of different management options, and evaluation of trade-offs and risks to overcome impediments to optimal decision-making.

Working Group Lead: Evan Grant (US Geological Survey Patuxent Wildlife Research Center, MA, USA)

Background: The Decision Science Working Group applies the theory, tools, and techniques from decision analysis to the complex decision-making process for mitigating the threat of *Bsal*, managing risk to native amphibian communities, and responding to *Bsal* detections in North America (Framework Actions 2 and 5; see Box 1). Application of decision science provides an effective interface between rapidly changing conditions in societal, policy, and science information, uncertainty, and operational planning, which together provide substantial benefits that facilitate effective and rapid decision-making in response to *Bsal* detection. The Decision Science Working Group is currently composed of members representing academic institutions and federal agencies (US Geological Survey, US Fish and Wildlife Service). Collectively, the group has decades of experience in decision science, amphibian and pathogen ecology, research, mathematical modeling, and direct work with managers.

Emerging diseases have the potential to affect social, economic, and ecological interests of North American resource managers, who are entrusted by society to manage protected areas and wildlife populations. Because they must consider multiple objectives, resource managers face difficult trade-offs for any disease management strategy. The complexity that arises in balancing numerous, competing demands on resource managers effectively limits our ability to identify and implement proactive management, representing a major challenge for developing management strategies for *Bsal* and other emerging infectious diseases. To date, there are no viable treatment options available for *Bsal*, which limits the alternatives available for managers until effective treatments are identified (the Research Working Group has identified research priorities to address this knowledge gap). Much uncertainty remains, which also makes choosing an

(untested) management action challenging. Decision science provides a framework for developing strategies and determining a course of action in the face of uncertainty. Additionally, even if treatments are identified, implementation may still be delayed if other management objectives are predicted to suffer; decision analysis helps identify optimal solutions across potentially competing management objectives.

Planning for the possible arrival of *Bsal* in North America illustrates several decision-making impediments common in the world of wildlife disease. First, despite calls for improved responses to emerging infectious diseases in wildlife, management is seldom considered until a disease has been detected in a population. Lack of resources (i.e., time, money, and personnel) are often cited as reasons for not taking pre-emptive actions, but reactive approaches often limit the potential for control and increase the total cost of a response. Second, while preventing the arrival of a pathogen is the most effective means of controlling emerging infectious disease, it is not fail-safe. Once present in a new area or population, emerging diseases have the potential to impact competing social, economic, and ecological interests of North American resource managers, and there are consequently difficult trade-offs for any given disease prevention or management strategy (e.g., optimal actions for managing a wildlife disease may result in declines in recreational or economic values). Finally, acting under high levels of uncertainty is a hallmark of wildlife disease management. Choosing an untested management action can be difficult for managers to justify to the public, and acting in the face of uncertainty depends a great deal on an individual manager's tolerance for risk.

The application of decision science is increasing among natural resource agencies, as it provides rational and transparent frameworks for managing disease. Decision science tools, such as cost-benefit analysis or portfolio decision theory, can help managers better understand the opportunity costs of proactive action versus inaction. Multi-criteria decision analysis can be used to help examine trade-offs among competing social, political, economic, and ecological objectives. Finally, decision trees, expected value of information, and Bayesian belief networks are useful tools for understanding risk tolerance and examining the trade-offs between managing despite uncertainty and delaying action to gain additional information. By using the tools from decision science to facilitate conversations between researchers and wildlife managers and identify optimal management strategies, the Decision Science Working Group can help navigate the common pitfalls of developing and implementing proactive management solutions for *Bsal* ahead of an invasion and plan for thoughtful responsive management once *Bsal* arrives in a population.

Since 2015, the Decision Science Working Group has made considerable progress on its initial goals. The inaugural meeting that led to the development of the North American *Bsal* Task Force was originally planned as a *Bsal* decision science workshop sponsored by the US Geological Survey. That workshop led to a report that was one of the *Bsal* Task Force's initial accomplishments (Grant et al. 2015) and helped springboard the first product of the Decision Science Working Group (Grant et al. 2017), which addressed proactive measures to forestall *Bsal* emergence in North America. Simultaneously with the formation of the *Bsal* Task Force, initial efforts of an independent subgroup that became the heart of the Decision Science Working Group came to fruition as their United States risk assessment for *Bsal* emergence was published (Richgels et al. 2016). The Decision Science Working Group's current goals are designed to help researchers and managers identify and address the kinds of decision-making impediments outlined above and to advance the overall Framework Actions of the *Bsal* Task Force (Box 1). Goals and priority actions per goal are described further in the *Bsal* Implementation Plan

(Appendix 5), and annual reports summarize the working group's activities (salamanderfungus.org).

Some major challenges to *Bsal* management include limited control options for the initial introduction of disease, widely dispersed populations over multiple states and regions, fragmented management authority by diverse agencies (state or provincial/territorial, federal, and non-profits), and deep uncertainties in ecological characteristics of the pathogen, populations, and effectiveness of potential treatments. The Decision Science Working Group goals below are designed to respond to these challenges, and many are interactive with other working groups, especially the Response & Control, Research, Data Management, and Outreach & Communication Working Groups.

Goal B.4.1: Identify critical research that has the highest value of information, which will lead to an improved ability to manage *Bsal*.

Rank: High

Rationale: Identification of critical research needs that impede decision-making is of paramount importance for responsive and proactive management of *Bsal* emergence in North America. The collaborative development of research priorities between land managers and researchers is an integral component for creating and evaluating effective and efficient management solutions.

Management Relevance: Despite calls for improved responses to emerging infectious diseases in wildlife, management is seldom considered until a disease has been detected in a population. Reactive approaches often limit the potential for control and increase the total cost of a response. By using the tools from decision science to facilitate conversations between researchers and wildlife managers and identify optimal management strategies, the Decision Science Working Group can help navigate the common pitfalls of developing and implementing proactive management solutions for *Bsal* ahead of an invasion and plan for thoughtful responsive management once *Bsal* arrives in a population. Acting under high levels of uncertainty is a hallmark of wildlife disease management, and the use of formal decision analytics (e.g., multi-criteria decision analysis, risk analysis, cost–benefit analysis within a structured or adaptive management framework, and portfolio decision theory) is increasing among natural resource agencies as a rational and transparent framework for managing diseases. Decision analytic approaches can examine trade-offs between managing despite uncertainty and delaying action to gain additional disease information. In addition, this framework can identify key trade-offs among competing objectives, which are often ignored but which can be highly influential in the final decision-making process and in optimizing management responses.

Financial Needs: 500,000 USD; unfunded at present.

Priority B.4.1.1: Coordinate a *Bsal* science experts workshop to collaboratively create a system diagram to help identify areas of greatest research need (i.e., regions within the system diagram that may facilitate the development of proactive management strategies). System, or influence, diagrams map ecological system components and relationships that lead to defined outcomes. Research priorities are generated for those areas of the system diagram where improved knowledge will have the greatest contribution to selecting

optimal management actions and can be formally assessed using decision-analytic tools. This work will be conducted in collaboration with the Research Working Group.

Goal B.4.2: Identify approaches to improve proactive management of *Bsal* when risk or competing objectives are impediments to action.

Rank: High

Rationale: Proactive management to forestall *Bsal* emergence reduces the need for crisis-management approaches that can be less effective, less cost-efficient, and potentially higher risk for values of concern, such as threatened species or personal property.

Management Relevance: Involvement of the natural resource management community in proactive measures to forestall *Bsal* transmission in North America has several strategic advantages: it raises awareness of the potential *Bsal* threat to native species; it increases the likelihood *Bsal* is detected before it gains a significant foothold on the continent; as biosecurity measures are enacted, there are likely “spillover” benefits to forestall transmission of other pathogens, microparasites, or invasive species that similarly affect endemic hosts; it improves management success; and it is cost-effective relative to reactive measures that may include long-term rescue of local endemic hosts at the risk they may become conservation reliant for their persistence.

Financial Needs: 500,000 USD; unfunded at present.

Priority B.4.2.1: Use simulation, modeling, and optimization techniques to identify optimal actions given various impediments (i.e., uncertainty or competing objectives).

Priority B.4.2.2: Using these models, evaluate possible trade-offs of action versus inaction and estimate costs of delaying action. Evaluate individual and agency risk tolerance and its effect on optimal actions under different levels and sources of uncertainty.

Goal B.4.3: Conduct and update *Bsal* risk assessments.

Rank: High

Rationale: Based on recent risk assessments, amphibian importation restrictions were instituted in the United States and Canada in response to the threat of *Bsal* invasion. Unfortunately, the banning of salamander imports is unlikely, by itself, to completely mitigate the risk of introduction and spread (OIE and IUCN 2014) of this disease. For example, restrictions on the movement of domestic birds in 2015 failed to prevent highly pathogenic avian influenza outbreaks, which were attributed to poor or incomplete adherence to biosecurity recommendations. In addition, *Bsal* has recently been detected on several commonly imported anuran species in addition to urodeles, and the complete range of *Bsal* amphibian hosts is unknown. Thus, while the US Fish and Wildlife Service and Environment and Climate Change Canada decisions are an excellent first step to protecting North American salamander species from *Bsal* introduction, here we further explore the effectiveness of the possible combination of

Bsal Implementation Plan

prevention strategies for mitigating risk from an emerging pathogen, using *Bsal* as a case example.

Management Relevance: Knowledge advances can be used to inform adaptive management processes, improving management efficacy. This cycle can be applied to decision science and risk assessments, where knowledge advances can be used to update parameters in risk models and to alter management and policy decisions. In the *Bsal* context, use of multiple *Bsal* prevention strategies, rather than reliance on a single measure, can be a more effective strategy to forestall *Bsal* emergence in North America. In addition to an import restriction on salamanders, addition of alternative measures warrant consideration.

Financial Needs: 200,000 USD; unfunded at present.

Priority B.4.3.1: Estimate the residual risk to populations after implementation of strategies (e.g., importation ban, clean trade certification, or other trade-based strategies) designed to reduce risk of introduction of *Bsal* into wild populations of amphibians in Canada, Mexico, and the United States.

Priority B.4.3.2: Identify how other actions, in combination, may further reduce risk to native amphibians. Remaining risk will be calculated for combinations of pre-introduction (proactive) and post-introduction (responsive) management actions.

Goal B.4.4: Frame *Bsal* management problems at regional and resource manager levels.

Rank: High

Rationale: This goal is the bulk of the work needed to plan and develop implementation strategies for management of *Bsal* risk. Several managers are working with the Decision Science Working Group to frame and evaluate their decision options for proactive *Bsal* management. Framing management problems as decisions can enable managers to identify possible proactive solutions. This approach recognizes context-specific constraints, such as agency mandates, trade-offs among other mission elements, and relevant uncertainties that must be accommodated in developing a response.

Management Relevance: Having natural resource managers work together with decision science specialists can expedite development of multiple effective management options for *Bsal* response that take diverse management contexts into consideration.

Financial Needs: 680,000 USD; unfunded at present.

Priority B.4.4.1: Engage resource managers at multiple scales (e.g., single protected area, regional, national) to develop decision frameworks, and specific and relevant measurable attributes, for their particular jurisdictions. Particular emphasis should be made to include objectives and metrics to understand trade-offs among habitats, amphibian populations, and pathogen occurrence and prevalence.

Priority B.4.4.2: Hold a series of structured decision-making workshops with managers (i.e., US Fish and Wildlife Service refuge biologists, regional land managers, Canadian Fish and Wildlife biologists, etc.) who have expressed interest in identifying where

proactive management can be implemented and what the barriers to implementing proactive management are across regions and management entities.

Priority B.4.4.2: Work with managers with complementary or spatially proximate at-risk populations to develop decision frameworks for linked decisions (i.e., actions chosen by one decision maker may affect the actions available to another decision maker). Examples would be identifying proactive management with and without importation restrictions or identifying optimal control strategies for neighboring protected area populations.

Goal B.4.5: Identify whether management should consider proactive, reactive, or a combination of management strategies, dependent on the presumed presence and spatial distribution of *Bsal*.

Rank: High

Rationale: A number of sampling designs may be useful for detecting the presence of the pathogen within and among populations, and work is underway to improve predictions of areas that may be at highest risk for declines should the disease be discovered. Data from a surveillance program without an associated state-dependent management plan (i.e., conditional on the state of the disease) of the appropriate scale, meaning one that matches the scale of a management decision, are of limited use; the design of an optimal program must consider the possible management responses for various scenarios. This work will be conducted in collaboration with the Surveillance & Monitoring and Research Working Groups.

Management Relevance: *Bsal* surveillance increases the likelihood of detection early in *Bsal* invasion of North America. Improving surveillance designs through the application of decision science tools can help maximize early-detection likelihoods, which increases the likelihood of a positive management response and is much more cost-effective.

Financial Needs: 360,000 USD; unfunded at present.

Priority B.4.5.1: Incorporate information from surveillance work into current risk assessments for *Bsal* and adjust surveillance efforts accordingly to incorporate prior expectation of *Bsal* occurrence and observations from a designed surveillance program.

Priority B.4.5.2: Given that previous risk assessments used a limited number of criteria to identify high risk areas, determine if other criteria can be included to improve risk assessments.



Southern Dusky Salamander (*Desmognathus auriculatus*). © Alberto López.

5. Surveillance & Monitoring

Objective: To facilitate and coordinate the surveillance of *Bsal* in North America.

Working Group Leads: Mike Adams (US Geological Survey, OR, USA); Jenifer Walke (Eastern Washington University, WA, USA); Olya Milenkaya (Warren Wilson College, NC, USA)

Past Working Group Lead: Hardin Waddle (US Geological Survey, FL, USA)

Background: A coordinated surveillance effort is aimed at detecting the initial introduction of *Bsal* into North America, thereby allowing for a more effective rapid response to forestall further transmission and helping to safeguard the native fauna of the continent (Framework Action 4; see Box 1). Management and conservation actions cannot proceed effectively without the fundamental information about when and where *Bsal* is introduced to North America. While opportunistic *Bsal* sampling improves the odds of detecting *Bsal* compared to not sampling at all (e.g., Muths et al. 2009), this haphazard approach is unlikely to detect *Bsal* at the onset of its invasion. Instead, the Surveillance & Monitoring Working Group aim is the early detection of *Bsal* to allow for an effective and rapid response, with the ultimate vision of conserving amphibian biodiversity.

Achieving a broad and robust surveillance network is difficult and expensive because of the labor involved. No single organizational entity has been identified that has this capacity. Instead, the emphasis has been on coordinating and encouraging sampling for *Bsal* by diverse partners such that something close to a reasonable level of surveillance is achieved. Initial efforts toward this goal are described below. However, because of the limitations of initial approaches, current efforts of the Surveillance & Monitoring Working Group are aimed at building an integrated network of partners in surveillance. This network will increase *Bsal* awareness, engage volunteer personnel and citizen scientists, utilize dispersed in-kind resources, and increase the amount of *Bsal* sampling.

Past Surveillance Efforts:

United States: In the United States, some sampling has been conducted by federal agencies. As part of the Surveillance & Monitoring Working Group's primary objective, a one-time major

sampling effort was conducted by the US Geological Survey Amphibian Research and Monitoring Initiative (ARMI) in 2014 to 2017 (Waddle et al. 2019, 2020). This effort included sample sites across the United States, with resources allocated according to the estimated risk of *Bsal* occurrence as per the risk assessment model results developed by Richgels et al. (2016). Over 10,000 amphibians (mostly salamanders) were sampled. *Bsal* was not detected (Waddle et al. 2019, 2020; data archived at amphibiandisease.org by the Data Management Working Group, see below). ARMI continues to sample at a very low level in select areas where resources allow. In addition, the US Fish and Wildlife Service has done some sampling using their National Wild Fish Health Survey funding. There is an ongoing effort to sample in Appalachia, which is one of the high-risk areas (Richgels et al. 2016).

In the United States and elsewhere, independent science investigations into *Bsal* detections from skin swabs of selected species in specific geographies are ongoing. For example, four reports of joint *Bsal* and *Bd* sampling in North America were published in Herpetological Review in 2017 (Olson 2019).

In addition to sampling, in the United States, an iNaturalist website was set up as way to gather observations from the public of sick or dead amphibians that might need follow-up investigation. Similarly, the Partners for Amphibian and Reptile Conservation (PARC) national Disease Task Team set up a Herpetofaunal Disease Alert System (HDAS; email reports to herp_disease_alert@parcplace.org; include photograph, species affected, location, other relevant episode information, observer's name; Gray et al. 2018) that provides another way to gather observations of sick or dead amphibians that might not otherwise be reported. At its start, communication occurred between iNaturalist and HDAS, although that connection has been dormant in recent years. Reports received via HDAS or, when available, through iNaturalist, are typically forwarded to the relevant state biologist, but in some cases, when deemed necessary, members of the Disease Task Team or state authorities can use their personal networks to help facilitate further investigation.

Canada: In Canada, the provincial and territorial governments are the lead jurisdiction for amphibian disease surveillance. The provinces of British Columbia (BC) and Ontario have conducted the most intensive *Bd* and *Bsal* monitoring programs to date. In Ontario, over 900 amphibians were sampled opportunistically along a latitudinal gradient over a four-year period (2014–2017). All samples were tested for *Bsal*, and all tests were negative (Christina Davy, Ministry of Natural Resources and Forestry, unpubl. data). In 2016, provincial biologists in BC sampled for *Bsal* within a small number of wild Rough-skinned Newt (*Taricha granulosa*) and captive (pet store) salamander populations on the south coast—one of the high-vulnerability zones identified by Yap et al. (2015). *Bsal* was not detected by quantitative polymerase chain reaction (qPCR) analyses in any swabs from the 82 wild newts and 15 captive salamanders sampled (Govindarajulu et al. 2017). In many provinces, including Alberta, Saskatchewan, Québec and Newfoundland, the current approach is one of passive surveillance in which *Bsal* investigations are triggered by unusual or mass amphibian mortality events. However, Ontario is considering low-level opportunistic sampling over the short-term, as resources allow. In addition, amphibians seized from the illegal pet trade will be tested for *Bsal* in BC.

The Canadian public can submit reports of sick or dead amphibians to the Canadian Wildlife Health Cooperative (CWHC). The CWHC is able to advise on the collection of carcasses for follow-up investigation and screens samples for diseases and parasites to assess the health of wild populations (CWHC 2019). Canadian provinces and territories may have additional reporting tools for sick or dead amphibians, such as the Government of British Columbia's

“Frogwatching” site, which is monitored by the provincial amphibian specialist. Disease reports from Canadian locations that are received by the HDAS email address are forwarded to provincial authorities in Canada, similar to state reporting of HDAS reports received in the United States.

Mexico: In Mexico, surveys aimed at identifying *Bsal* in natural populations have been conducted by members of Gabriela Parra-Olea’s research laboratory at the Instituto de Biología, Universidad Nacional Autónoma de México (UNAM). So far, 119 individuals of 41 species (frogs and salamanders) have been sampled, and *Bsal* has not been detected by qPCR analyses in any of the swabs (Parra-Olea, unpubl. data). Additional surveys by Eria Rebollar (Centro de Ciencias Genómicas, UNAM) and Gabriela Parra-Olea in plethodontid salamanders and *Ambystoma* species across the Trans-Mexican Volcanic Belt were planned for 2020 but had to be postponed because of COVID-19 restrictions on travel and teaching. Parra-Olea and Rebollar have begun efforts to provide certification to both of these research laboratories so that legal amphibian imports in Mexico can be screened for *Bsal*.

The Surveillance & Monitoring Working Group has strong ties to the Data Management Working Group, which helps compile *Bsal* surveillance reports and scientific studies from outside the efforts of the North American *Bsal* Task Force (Goal B.5.2). They also coordinate with the Diagnostics Working Group, which conducts *Bsal* diagnostics research, and the Response Working Group to help formulate monitoring responses if *Bsal* were to be detected. As needed, they work with the Clean Trade Working Group for Goal B.5.3 and the Decision Science Working Group, as their risk assessments have guided initial priority sampling efforts.

Goal B.5.1: Facilitate and support a wide-reaching, ongoing, coordinated, and sustainable *Bsal* surveillance program in Canada, Mexico, and the United States.

Rank: High

Rationale: A robust surveillance network is needed for early detection of *Bsal* upon introduction. The earlier *Bsal* is detected, the better the chance of containment and of limiting negative consequences for amphibian biodiversity.

Management Relevance: Early detection of *Bsal* in North America improves management efficacy to forestall *Bsal* spread, increasing population and species persistence likelihoods at lower financial burdens. It is a win-win strategy for retaining North American amphibian biodiversity and reducing stressors to the larger ecosystems within which amphibians are embedded.

Financial Needs: In-kind support from member agencies and institutions (especially US Geological Survey’s Amphibian Research and Monitoring Program) for personnel time, some laboratory analyses, and travel. Grant proposals are planned for partner sampling efforts, travel, and laboratory analytical costs. Estimated costs: 15,000 USD per year for the Student Network for Amphibian Pathogen Surveillance (SNAPS) portion of Priority B.5.1.1; 100,000 USD per year in 2021–2023 for initial efforts with broader surveillance in Canada, Mexico, and the United States; 200,000 USD per year for scaled-up efforts in 2023–2025.

Priority B.5.1.1: Establish a *Bsal* surveillance program in cooperation with colleges and universities: the Student Network for Amphibian Pathogen Surveillance (SNAPS). This priority includes development of partnership roles, a student training curriculum, sampling protocols, safety and biosecurity procedures, data procedures, and procedures to obtain necessary permits and permissions for working with wildlife and working with students within course constraints or as part of extracurricular activities.

Priority B.5.1.2: Facilitate and support ongoing *Bsal* surveillance in Mexico and Canada.

Goal B.5.2: Identify *Bsal* sampling efforts that are occurring outside of efforts coordinated by the *Bsal* Surveillance & Monitoring Working Group.

Rank: High

Rationale: Researchers and managers are conducting their own *Bsal* surveillance across North America outside of efforts spearheaded by the *Bsal* Task Force, but these efforts are not coordinated. Therefore, to maintain an ongoing account of the entire *Bsal* surveillance effort, this working group should at least contact these principal investigators (PIs) and catalogue their efforts.

Management Relevance: Multipronged, coordinated surveillance has a higher likelihood of detecting *Bsal* early upon its emergence in North America, reducing long-term management costs of *Bsal* management and protection of rare species. Coordination of efforts can reduce survey redundancies, provide better inference to North America and host taxa, and be more cost-efficient. Strategic coordination may influence independent sampling in much needed areas where gaps in effort have been revealed.

Financial Needs: In-kind support from member agencies and institutions for personnel time, some laboratory analyses, and travel. Grant proposals are planned for partner sampling efforts, travel, and laboratory analytical costs. No cost estimates are available at this time, as the workplan is still in development.

Priority B.5.2.1: Coordinate with the *Bsal* Research Working Group and other amphibian disease researchers across North America who are conducting *Bsal* surveillance as part of their broader research programs.

Priority B.5.2.2: Establish additional pathways of communication with a broader sector of amphibian biologists, permitting agencies and institutions, and diagnostic laboratories to develop a means of identifying personnel conducting *Bsal* surveillance without compromising confidential research plans.

Priority B.5.2.3: Encourage *Bsal* and *Bd* surveyors to input their planned, ongoing, or past efforts into the chytrid data management portal, amphibiandisease.org.

Goal B.5.3: Support and facilitate sampling of amphibians in the pet trade.

Rank: High

Rationale: *Bsal* is likely to be introduced to North America through amphibian trade. Therefore, surveillance among captive amphibians is a logical priority for the early detection of *Bsal*. Furthermore, detection of *Bsal* in captive animals prior to its introduction in the wild will provide conservationists and managers with the opportunity to contain the pathogen and prevent it from affecting wild populations.

Management Relevance: Forestalling *Bsal* introduction to the wild in North America is of premier importance for retaining the integrity of North American wildlife and ecosystems, a primary goal of natural resource managers. Early *Bsal* detection in North American trade markets and captive populations (e.g., amphibians used as pets, food, and traditional medicines and populations retained in zoos, aquariums, museums, and biomedical research) can improve *Bsal* management efficacy and reduce costs of *Bsal* mitigation actions in North America.

Financial Needs: In-kind support from member agencies and institutions for personnel time, some laboratory analyses, and travel. Grant proposals are planned for partner sampling efforts, travel, and laboratory analytical costs. No cost estimates are available at this time, as the workplan is still in development.

Priority B.5.3.1: Coordinate with the newly established Clean Trade Working Group to support and facilitate *Bsal* sampling of amphibians in the pet trade.

Priority B.5.3.2: Develop a study plan for animal sampling or subsampling and eDNA water sampling for *Bsal* at ports of entry.

Priority B.5.3.3: Develop study plan for animal subsampling and eDNA water sampling of batches in pet stores in cooperation with state and provincial/territorial agencies.

Goal B.5.4: Develop initial plans for post-detection monitoring if *Bsal* were to be detected at a field or captive site in North America.

Rank: Urgent

Financial Needs: In-kind support from member agencies and institutions for personnel time.

Priority B.5.4.1: In cooperation with the Decision Science Working Group, partners, and existing scenario-development exercises of *Bsal* detection in different site geographic and taxonomic contexts, develop example sampling designs to detect the extent of *Bsal* at a novel detection site before mitigation actions are fully implemented.

Priority B.5.4.2: In cooperation with the Decision Science Working Group, partners, and existing scenario-development exercises of *Bsal* detection in different site geographic and taxonomic contexts, develop example sampling designs to detect the extent of *Bsal* at a detection site after different types of mitigation actions are fully implemented.

Priority B.5.4.3: To fine-tune monitoring designs at known or suspected *Bsal* detection sites, develop study plans to compare efficacy of alternative approaches; develop a priori Institutional Animal Care and Use Committee (IACUC) and state or federal permission forms and determine if expedited approvals could be gained.



Apalachicola Dusky Salamander (*Desmognathus apalachicolae*). © Alberto López.

6. Data Management Working Group

Objective: To develop an online *Bsal* and *Bd* data management portal to accelerate sharing of planned or completed surveillance projects and scientific studies to accelerate the pace of learning about these pathogens tied to emerging infectious diseases and foster integrated efforts in research and monitoring across North America and among global communities.

Working Group Leads: Michelle Koo (AmphibiaWeb, University of California, CA, USA); Deanna H. Olson (USDA Forest Service, OR, USA)

Background: The Data Management Working Group is a multi-partner collaboration to retain a *Bsal* and *Bd* database of world amphibian-chytrid occurrences and projects for co-production of knowledge to improve the science and management of these pathogens. In particular, this working group works closely with other groups in the *Bsal* Task Force, the University of California at Berkeley (UC Berkeley) and its online collaborative resource [AmphibiaWeb.org](https://amphibiaweb.org), and the US Forest Service, manager of the world *Bd* database through 2019, in previous collaboration with Imperial College, London (Olson et al. 2013, Olson and Ronnenberg 2014). Underscoring all sources of *Bsal* and *Bd* data are the independent investigators who have been vital to compiling and disseminating *Bsal* and *Bd* surveillance results. These data are now available via development of an accessible web portal database with data import and export, analysis, and multi-database linking functions (Framework Action 5 and 8; see Box 1). A web portal reporting system for *Bsal* and *Bd* data provides larger-scale data management capabilities and can address novel multi-scale questions and metadata analyses across individual studies. This data-sharing capability can contribute to analyses that advance understanding of the risk of *Bsal* or *Bd* introduction to North America and assess disease risk of these potentially deadly pathogens to native amphibians in North America and elsewhere through aggregating and managing past and current disease sampling data in a common repository.

The Data Management Working Group has met its original goal by developing the Amphibian Disease Portal (amphibiandisease.org) to comprehensively manage data on *Bd* and *Bsal*. This standards-compliant, online portal is hosted as the Disease Portal webpage on

AmphibiaWeb.org, managed by UC Berkeley. The portal, which includes public and private datasets, is aimed at accelerating information sharing among global scientists, natural resource managers, and the public regarding planned and ongoing surveillance projects and scientific studies as well as the results of completed studies. Data within the portal are especially important for aiding in rapid responses and decision science for allocation of limited resources available for research and management of these amphibian emerging infectious diseases and their affected hosts. In particular, comprehensive management of *Bd* and *Bsal* detection and no-detection data by location and project is useful for development of new scientific research studies, surveillance, and effective monitoring programs and for understanding disease dynamics of chytridiomycosis. Through its website, in particular the Data Dashboard, the Amphibian Disease Portal could be an effective outreach and technical interface for the research community. Further, links to other online scientific portals, such as AmphibiaWeb, help extend the portal's reach to other audiences in education and conservation.

The Data Management Working Group is allied with the Surveillance & Monitoring, Research, Decision Science, and Outreach & Communication Working Groups, with anticipated potential interaction with the Clean Trade Working Group.

Goal B.6.1. Maintain comprehensive data management of *Bd* and *Bsal* samples for archived, aggregated monitoring and analytic modeling in the Amphibian Disease Portal (amphibiandisease.org).

Rank: Urgent

Rationale: The Data Management Working Group aims to expand the scope and capacity of the new web-based Amphibian Disease Portal (amphibiandisease.org). In addition to increasing registered portal users and *Bsal* and *Bd* data imports, the Amphibian Disease Portal is partnering with the global bio-sampling database Geome (geome-db.org) to enhance research and forecasting abilities by 1) delivering improved validation services, 2) enhancing security, and 3) improving data accessibility through third-party applications and programming tools (e.g., R statistical software and Python language applications). These developing functional capacity priorities of the web portal are described in the *Bsal* Implementation Plan (Appendix 5). Goals and priority actions per goal are described further in the *Bsal* Implementation Plan (Appendix 5), and annual reports summarize the working group's activities (salamanderfungus.org).

Management Relevance: The portal serves as a data management system for chytrid survey information and a communication mechanism among surveillance teams to show where efforts are planned, ongoing, or completed. This approach maximizes early detection of *Bsal* in North America and is cost effective because redundant efforts are not launched. Early detection reduces future potential costs to natural resource managers for sustaining or restoring their natural systems.

Financial Needs: In-kind support from member agencies and institutions for personnel time and travel. Grant proposals are planned for temporary hiring of web programmers to advance web user interfaces and database management procedures. Estimated costs: 30,000 USD per year for web developer to create SNAPS website for use by colleges and universities across the United States; 10,000 USD per year for *Bd* and *Bsal* data updates from the literature.

Priority B.6.1.1: Import *Bsal* surveillance projects and associated data into the portal as projects are planned (e.g., SNAPS, discussed by Surveillance & Monitoring Working Group above) and completed and data become available from *Bsal* Task Force partners and independent researchers.

Priority B.6.1.2: Develop systems and networks to identify data from *Bsal* surveillance and science reports.

Priority B.6.1.3: Update and upload the independent world *Bd* database from Bd-maps.net (2007–2014) and updates to it (through 2019) developed by the Global *Bd* Mapping Project managed by the US Forest Service Pacific Northwest Research Station (Olson et al. 2021); this larger *Bd* database (2007–2019) serves as a model for *Bsal* data management, and lessons learned from *Bd* data management can improve *Bsal* data management efficiencies.

Priority B.6.1.4: Improve collaborations with other *Bsal* Task Force working groups, including Surveillance & Monitoring, Decision Science, Research, and Outreach & Communication, for planning of sampling efforts and coordinating outreach for improved surveillance efficiencies across North America.

Goal B.6.2: Advance the functional capacity of the Amphibian Disease Portal (amphibiandisease.org).

Rank: High

Rationale: Web portal management and improvements are dynamic as security systems adapt and technology advances, enabling broader analysis applications and weaving of multiple datasets across websites.

Management Rationale: Improving portal functional capacities attracts more users to the site, improving data inclusivity and expanding analytical capabilities. The result is enhanced understanding of *Bsal* current and future distributions and host taxonomic patterns of infection and disease. Such knowledge can guide management actions for *Bsal* mitigation or host species biosecurity.

Financial Needs: In-kind support from member agencies and institutions for personnel time. Grant proposals are planned for temporary hiring of web programmers to advance web user interfaces and database management procedures. Estimated costs: 10,000–25,000 USD per year for web-programmer upgrades; 70,000 USD for data scientist programmer for one year.

Priority B.6.2.1: Facilitate data import and export procedures and add new analytical applications for access.

Priority B.6.2.2: Expand web programming to enhance analytical capacities, e.g., incorporate interactive web displays of data and correlation charts or modeling.

Priority B.6.2.3: Expand integration capacity among databases, for example, to better integrate with the AmphibiaWeb portal with reciprocal links and access to geographic, habitat, or climate databases and other enhancements, such as the ability to update data with current species taxonomic information.



Marbled Salamander (*Ambystoma opacum*). © Eric Isselée.

7. Outreach & Communication Working Group

Objective: To facilitate *Bsal* communication and outreach in North America.

Working Group Leads: Mark Mandica (Amphibian Foundation, USA); Alex Shepack (University of Notre Dame, IN, USA)

Past Working Group Lead: Jillian Farkas (University of South Dakota, SD, USA)

Background: The Outreach & Communication Working Group produces a variety of *Bsal*-related outreach communication materials, including a web presence (salamanderfungus.org), fact sheets, press releases, lay and scientific articles, briefing papers, blog posts, and social media posts (Facebook and Twitter). In particular, the Outreach & Communication Working Group works with the Technical Advisory Committee (TAC) and its partners and other working groups within the *Bsal* Task Force to disseminate new *Bsal* information and products developed by the group and others. To increase the efficacy of dissemination, the Outreach & Communication Working Group continues to build an online network via social media, increasing followers and directing them to the salamanderfungus.org website, which serves as a hub and repository for published developments relating to issues, detections, and research regarding *Bsal*.

Although the Outreach & Communication Working Group is not tasked with conducting or publishing *Bsal* research, members help synthesize findings and communications from other groups within the *Bsal* Task Force for the purposes of producing lay articles meant to educate the public and highlighting key messages in social media posts. The scope of outreach to date has focused on national coverage in the United States, as there are salamanders at risk throughout the United States. Outreach may also be relevant for Canada and Mexico, but focused efforts outside the United States have not yet been initiated by the working group.

Finally, the Outreach & Communication Working Group organizes, designs, and publishes the annual report for the *Bsal* Task Force. This annual report summarizes advancement within all working groups and the current status of the *Bsal* fungus. This report is published on salamanderfungus.org and is available to both the general public and the scientific community. Goals of the working group are listed below, and priority actions per goal are described further in the *Bsal* Implementation Plan (Appendix 5; salamanderfungus.org).

Goal B.7.1. Work with partners to disseminate syntheses, research, and other products or activities developed by the *Bsal* Task Force via social media and newsletter articles.

Rank: High

Rationale: Build a network of partners to publish updates on *Bsal* developments and serve as an efficient mechanism for alerting the public and scientific community in the event of a positive United States detection of *Bsal*.

Management Relevance: This communication group is a dominant resource for management agency information about *Bsal*. Forging these networks of communication before *Bsal* is detected in North America will facilitate communication during a potential crisis, such as a die-off, allowing for a more measured and effective response.

Financial Needs: In-kind support from member agencies and institutions for personnel time and travel; some grant proposals are anticipated. There are no cost estimates available at this time.

Priority B.7.1.1: Echo *Bsal* information and key findings of new scientific research publications in new publication outlets.

Priority B.7.1.2: Develop publication partner relations.

Priority B.7.1.3: Provide outreach for new programs and operations of the *Bsal* Task Force, such as development of SNAPS with colleges and universities (see Surveillance & Monitoring, above).

Priority B.7.1.4: Provide media releases of *Bsal*-related information for relevant United States national or North American events.

Goal B.7.2: Continue to build a network on social media to communicate developments within the *Bsal* Task Force.

Rank: Urgent

Rationale: Social media is a powerful communication tool that can reach different sectors of the community. Building a network of social media partners can expand the *Bsal* Task Force purpose and aims.

Management Relevance: Outreach via social media can connect broader citizen scientists and the public to *Bsal* efforts, enhancing awareness and improving partnerships with natural resource specialists in institutions and agencies.

Financial Needs: In-kind support from member agencies and institutions for personnel time and travel; cost estimate: 2,500 USD.

Priority B.7.2.1: Explore utility of additional media applications for outreach and communication.

Priority B.7.2.2: Build social media presence.

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Priority B.7.2.3: Summarize new information for newsletters, blogs, and social media posts.

Goal B.7.3: Independently, or with partners, produce public service announcements on the presence and implications of *Bsal*.

Rank: Medium

Rationale: Multimedia communication can reach broader audiences.

Management Relevance: Multimedia communication can reach agency managers and, as they are partners with common goals, be used by them for their own messaging.

Financial Needs: In-kind support from member agencies and institutions for personnel time; cost estimate: 6,000 USD.

Priority B.7.3.1: Work toward development of film or video outreach materials; identify videographers, develop material with the TAC, and produce videos.

Priority B.7.3.2: Work toward development of communication products (e.g., additional flyers, briefing papers) on *Bsal*; identify a printer, develop materials and content with the TAC, print and ship to partners.

Goal B.7.4: Update the *Bsal* Task Force website.

Rank: High

Rationale: The website is a go-to resource for North American *Bsal* information, including updated recent news.

Management Relevance: Natural resource managers access the website for rapid information used in their decision making.

Financial Needs: In-kind support from member agencies and institutions for personnel time; cost estimate: 3,000 USD yearly.

Priority B.7.4.1: Work with TAC members or partners, including the Amphibian Survival Alliance, to restructure and repopulate a more navigable website structure.

Priority B.7.4.2: Work with TAC members or partners, including the Amphibian Survival Alliance, to develop working group web pages and content.

Priority B.7.4.3: Work with TAC members or partners, including the Amphibian Survival Alliance, to develop a better *Bsal* publications list for the website and maintain updates to this list.



Spotted Dusky Salamander (*Desmognathus conanti*). © Alberto López.

8. Clean Trade Working Group

Objective: To expand efforts to forestall potential human-mediated transmission of *Bsal* into North America via trade markets.

Working Group Lead: Josh Jones (Pet Industry Joint Advisory Council, VA, USA)

Background: Although *Bsal* was first described from infections of Fire Salamanders in Europe, an Asian origin of the pathogen was implicated from the outset (Martel et al. 2013). Additional support for the hypothesis that *Bsal* evolved in Asia has been forthcoming. No lethal infections have been found there, suggesting that a long co-evolutionary history has led to resistance or tolerance by amphibian species in Asia (Laking et al. 2017). In Europe, infections were first observed in the Netherlands (Spitzen-van der Sluijs et al. 2016), followed by the discovery of *Bsal* in Belgium and Germany (Stegen et al. 2017, Lötters et al. 2020) and most recently in Spain (Martel et al. 2020). The lethal effect of *Bsal* on some European amphibian species suggests a recently arrived pathogen that has encountered naïve hosts. The likely routes of within-continent spread are dispersal of infected amphibians among populations; possibly movement of spores by waterfowl, other wildlife, and humans; and spillover of infected individuals once held in captivity (Nguyen et al. 2017, Yuan et al. 2018). Spread of *Bsal* between continents, including the emergence of *Bsal* in Europe, is likely due to importation of infected species from locations where *Bsal* is endemic (Nguyen et al. 2017). Anurans from Asia infected with *Bsal* have been found in a pet store in Germany (Nguyen et al. 2017, Yuan et al. 2018). In addition, *Bsal* has been found on salamander species in China that are frequently imported. These findings suggest a role of trade markets in the between-continent spread of *Bsal*. In particular, the discovery that anurans can be infected opens up the possibility that trade in frogs for food, research, and pets can lead to between-continent dispersal. Clean trade measures, such as development of *Bsal* testing and certification procedures that help ensure traded animals and fomites in imports to North America are *Bsal*-free, are likely the most effective proactive measures for forestalling *Bsal* emergence in North America (Grant et al. 2017). Such measures align with Framework Action 1 (Box 1).

The Clean Trade Working Group was established in early 2020 in partnership with the Pet Industry Joint Advisory Council (PIJAC), and its implementation goals and priorities are under development at this time. The objective of the stakeholder-led Clean Trade Working Group is for experts in the pet trade to organize and collaborate with subject matter experts, regulators, and academics to determine what the potential components of a workable, comprehensive clean trade program for North America may include and to report these initial findings back to the *Bsal* Task

Force Technical Advisory Committee (TAC). Currently, this working group has established a network of experts in amphibian and reptile care, husbandry, and pathogen and disease research, including industry experts with knowledge of the volume and dynamics of the amphibian trade. This group has been collaborating on a regular basis to identify potential components for a comprehensive North American clean trade program to help prevent the invasion of *Bsal* to North America while allowing for the legal and responsible importation of animals for the pet trade. For example, components under discussion at this time include a description of the current status of amphibian imports; a characterization of the United States and Canada amphibian trade network; and identification of factors or processes that could reduce potential pathogen transmission, amplification, and spillover.

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