A Systematic Assessment of Invasive Species Impacts to Species at Risk in BC

FINAL REPORT

June 30, 2021

Invasive Species Council of BC

ESSA

Prepared for the Invasive Species Council of BC

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1 Executive Summary

Invasive species (IS) are one of the top five drivers of species extinctions and biodiversity loss worldwide (IPBES 2019). In Canada, IS are frequently and increasingly identified as top threats to species at risk (SAR) (McCune et al. 2013, Woo-Durand et al. 2020), however, the precise nature, extent, and severity of these threats has not been systematically characterized. This represents a potentially serious knowledge gap given the urgent need for management interventions to help prevent the extirpation of species on the brink, particularly in light of the accelerating rate of species invasions across the globe. Improving our understanding of the ways in which IS are impacting SAR will provide a stronger foundation for the development of more focused research, education, and management strategies to help reduce or mitigate these threats. To illustrate the value of this information, this study set out to undertake a systematic assessment of the impacts of IS on SAR in Canada's most biologically diverse province, British Columbia (BC). IS are known to have direct and indirect impacts on hundreds of species in BC. This landscape of high invasion pressure is also inhabited by over 200 native species formally listed under Canada's federal *Species at Risk Act*, 2002 as well as and hundreds more assessed as being at risk by the federal Committee on the Status of Endangered Wildlife in Canada or by the Province of BC's Conservation Data Centre. Building on two previous national studies (McCune et al. 2013, Woo-Durand et al. 2020), this review synthesizes the impacts that priority IS are having on federally-listed species at risk in BC across 784 unique SAR-IS pairs.

Key Findings

- Most IS impacting SAR were accidentally introduced and are now spread through a range of human activities, many of which are associated with the recreational sector.
- Habitat degradation and alteration, competition, and predation are the most common mechanisms of impact of IS on SAR, though other mechanisms (e.g., disease, genetic effects) emerge as disproportionately important for a subset of SAR taxa.
- The magnitude of threats posed by IS are generally rated in SAR assessments as being pervasive, ongoing, and seriously or extremely severe for a majority of affected SAR in most taxonomic groups.
- As might be expected, the distributions of SAR affected by IS roughly coincide with regions of the province associated with the largest populations and concentrations of human activities likely to contribute to IS spread and persistence.
- The other threats most often faced by SAR impacted by IS are human intrusions or disturbances and development.
- Some IS have a disproportionate level of impact on multiple SAR (~10-30), SAR tend to be most impacted by species in the same taxonomic group. Both the most impacting IS and the most impacted SAR in the province are dominated by plants.

Key Insights for Management Strategies

By holistically examining the impacts that IS are having on SAR in BC, many valuable insights for building management strategies have emerged. Findings from this review can help prioritize:

- ➔ Interventions to target SAR that are most vulnerable to IS impacts.
- ➔ IS interventions that will assist the widest range of SAR.
- ➔ Most effective management interventions, based on mechanisms of IS impact.
- ➔ Public outreach campaigns to target common vectors of introduction and spread.

This research can also feed new information into existing prioritization tools such as cost-benefit analyses, feasibility studies, and trade-off assessments.

Potential Avenues for Future Work

This review has revealed several promising avenues of future research that build on the foundation of our work. Avenues for future work include:

- ➔ Devoting additional resources to filling remaining gaps in this data set, to the extent that the information is available.
- ➔ Conducting a spatially explicit analysis of the actual distributional overlaps between IS and the SAR that they impact to prioritize limited management resources, tailor interventions to regionally specific mechanisms of dispersal, and identify IS-SAR interactions in areas of significance to Indigenous peoples.
- ➔ Better understanding the management implications of IS threats against the backdrop of climate change, which poses a key threat to biodiversity and presents even greater challenges when paired with threats posed by IS.
- ➔ Expanding this work to a national scale to inform management planning in other regions of Canada, as well as national recovery planning for SAR.

This work contributes to a greater understanding of which IS pose the greatest threats to SAR in BC as well as how, how much, and where these impacts are occurring, to inform future research and management priorities. In the regional context, this work directly supports the objectives of the Road Map for Invasive Species Research in BC (ISCBC 2020) by identifying current gaps in IS management, highlighting potential research priorities, and strengthening support for IS research in the province, as well as those of a number of provincial invasive species management strategies, including the Invasive Alien Species Framework for BC (Rankin et al. 2004), the Invasive Species Strategy for British Columbia (ISCBC 2012), and the Invasive Species Strategic Plan for BC (IMISWG 2014). More broadly, this work serves as a case study demonstrating how the systematic documentation of IS-SAR interactions can help guide the development of response strategies that make the best use of limited management resources.

2 Introduction

The rate of alien species invasions and the number of established alien species has risen drastically over the past fifty years and, today, invasive species (IS) are considered to be one of the top five drivers of species extinctions worldwide (IPBES 2019). Moreover, rates of established alien species are predicted to further increase in coming years (Seebens et al. 2021). Drivers of invasion for IS include increasing human mobility, expanding global trade networks, continuing habitat degradation, and accelerating climate change. Some geographic patterns of IS impacts are known at a global scale. For instance, high-income countries in North America, Europe, and Australasia are known IS hotspots (IPBES 2019). These hotspots are characterized by higher gross domestic product per capita and higher population densities (Dawson et al. 2017). In addition, hotspots are often island or coastal regions. While these broad, global patterns of IS drivers and impact have emerged in recent years, the specific impacts of IS on species at risk (SAR) remain understudied and represent a key area of research for informing management strategies for IS and for the conservation of global biodiversity.

Canada is an example of a high-income, North American country in which IS are frequently and increasingly identified as a top threat to SAR (McCune et al. 2013, Woo-Durand et al. 2020). However, the precise nature, extent, and severity of the threats posed by invasive species to SAR have not been systematically characterized in Canada. This represents a potentially serious knowledge gap given the urgent need for management interventions to help prevent the extirpation of species on the brink, particularly in light of the accelerating rate of species invasions across the globe. Improving our understanding of the ways in which IS are impacting SAR will provide a stronger foundation for the development of more focused research, education, and management strategies to help reduce or mitigate these threats.

This study set out to undertake a systematic assessment of the impacts of IS on SAR in Canada's most biologically diverse province, British Columbia (BC), to illustrate the value of this approach. As a coastal region with areas of high population density and a high gross domestic product per capita, BC has the hallmark traits of an IS hotspot that are manifested in extensive documentation of broad ecological (e.g., Rankin 2004, Gayton 2007) and economic (e.g., Frid et al. 2009, Robinson et al. 2013) impacts of these species in the region. This landscape of high invasion pressure is also inhabited by over 200 native species formally listed under Canada's federal *Species at Risk Act*, 2002 (SARA) as well as and hundreds more assessed as being at risk by the federal Committee on the Status of Endangered Wildlife in Canada (COSEWIC) or by the Province of BC's Conservation Data Centre (CDC). While some work has examined the habitat-specific impacts of IS on BC SAR (Voller and McNay 2007), much remains unknown about the nature of their ecological impacts across the province.

Our work contributes to a greater understanding of which IS pose the greatest threats to SAR in BC as well as how, how much, and where these impacts are occurring to inform future research and management priorities. In the regional context, this work directly supports the objectives of the Road Map for Invasive Species Research in BC (ISCBC 2020) by identifying current gaps in IS management, highlighting potential research priorities, and strengthening support for IS research in the province, as well as those of a number of provincial invasive species management strategies, including the Invasive Alien Species Framework for BC (Rankin et al. 2004), the Invasive Species

Strategy for British Columbia (ISCBC 2012), and the Invasive Species Strategic Plan for BC (IMISWG 2014). More broadly, this work serves as a case study demonstrating how the systematic documentation of IS-SAR interactions can help guide the development of response strategies that make the best use of limited management resources.

3 Methods

3.1 Species Screening

Our approach to this systematic assessment relied on implementing screening criteria to focus our efforts on a subset of all SAR potentially impacted by IS in BC.

Species screening began with all the COSEWIC assessments for BC and/or Pacific Ocean species available on Canada's Species at Risk Public Registry (https://www.sararegistry.gc.ca/) as of September 2020. This list was then filtered in a first-pass screening to include only SAR (i.e., species with a COSEWIC status of 'non-active' or 'not at risk' were excluded). The remaining assessments were merged with data from two previous studies of threats to Canadian SAR (McCune et al. 2013, Woo-Durand et al. 2020) which identified SAR listed on the Species at Risk Public Registry for whom invasive or other problematic species were noted as an important contributor to threat status. However, we also reviewed all pertinent documentation released after the publication of these prior studies (i.e., SARA recovery strategies published after 2012 and COSEWIC assessments published after 2018) to reflect the most current understanding of IS impacts on SAR at the time of writing.

Those SAR remaining after this first-pass screening underwent a second-pass screening through rapid literature review to confirm documented threats by invasive species, as opposed to threats by problematic native species. In this second-pass screening, available COSEWIC assessments and status reports, recovery strategies, and management plans for each SAR were searched for the terms 'invasive', 'non-native', 'alien', 'exotic', and 'introduced'. Attention was primarily given to the use of those terms in the sub-section entitled 'invasive & other problematic species and genes' in the 'Threats' section of the documents, however, information provided about invasive species elsewhere in the document was also noted. It should be noted that the COSEWIC and SARA documents provide information on past, present, and future threats from invasive and problematic species – all of these threats were retained if there was reason to believe they were relevant in the BC context. This means that in a few cases, an IS that is not yet reported in BC has been documented as a threat to a BC SAR because the documents suggest that its range will expand into BC in the future.

Finally, we applied a third-pass screening to narrow down the overall list to only those SAR flagged as being impacted by at least one IS on BC's Provincial Priority Invasive Species List (BC IMISWG 2020, hereafter referred to as the Priority List), which identified IS within the region considered to be management priorities as a result of their impacts and/or management potential. Applying this additional level of screening maximizes the potential utility of our study results for applied management planning.

It should be noted that although the Priority List was used to refine our overall list of SAR, impacts of IS that are not on the Priority List were still documented for the focal SAR where these were mentioned in documentation reviewed. Moreover, our review applies a broad definition of IS that includes any non-native species that may be impacting SAR, whereas some of these species are only regionally non-native and may be considered native elsewhere in BC.

The SAR remaining after these screening steps constituted the focal species for a more detailed literature review intended to document the nature and extent of invasive species impacts.

3.2 Detailed Literature Review

We carried out a systematic literature review on our list of focal SAR, beginning with a detailed review of COSEWIC assessments and status reports, recovery strategies, and management plans available on the Species at Risk Public Registry.

The following essential characteristics of each SAR were recorded: common and scientific name, taxon, population name (if applicable), COSEWIC Conservation Status, last COSEWIC assessment date, SARA Schedule 1 Status, date listed under SARA, primary habitat type(s), and, if available, the importance of the species to Indigenous peoples. The species distribution information available in these reports was broadly documented as presence or absence within each of BC's Ecoprovinces (as established using the provincial Ecoregion Classification System – see Demarchi 2011).

For each SAR, each individual IS species or species group noted as posing a threat was also recorded and the details of interactions for each SAR-IS pair documented. We recorded whether each SAR-IS interaction was documented in a COSEWIC assessment and status report, recovery strategy and/or management plan, or both. A narrative description of invasive species impacts on the SAR was captured, as well as a description of any specific geographic areas in which the threat from IS occurs. Other variables pertaining to the SAR-IS relationship that were recorded as part of this literature review included: mechanism(s) of threat/impact, vector of introduction, year of introduction, magnitude of the threat/impact and confidence in the magnitude of the threat/impact, notable information gaps about impacts, and a summary of any documented strategies and conservation measures focused on mitigating the invasive species threat.

Magnitude of the threat / impact of invasive or problematic species was typically reported using one of two kinds of standardized threat calculators, an IUCN Threat Calculator (Master et al. 2012, COSEWIC 2019) or a separate non-IUCN threat calculator developed specifically for use in Canada (DFO 2014). To perform pooled analyses on magnitude of threat data, these two data types were reconciled by matching threat magnitude rating from the non-IUCN threat calculator to the closest corresponding threat magnitude rating in the IUCN Threat Calculator (see supplementary materials in ---

Appendix C for further details). These calculators provide one rating for the cumulative threat from invasive and problematic species, therefore the magnitude of the threat / impact cannot be fully attributed to invasive species alone. It should also be noted that, when the magnitude of a threat is not uniform across a SAR's range, the threat calculator may provide a range of ratings (e.g., Moderate-High) for scope, severity, timing, or impact. For analyses using threat calculator ratings, we defaulted to the most severe rating in the range for use in analysis following the precautionary principle.

In addition to reviewing documents available on the Species at Risk Public Registry, we conducted additional internet searches for peer-reviewed and white paper documents to fill remaining information gaps about each SAR-IS relationship. These additional searches focused primarily on supplementing information about the vectors of initial introduction and vectors of ongoing spread for the IS. Lastly, other notable threats to each SAR beyond invasive species that had been previously documented by McCune et al. (2013) and Woo-Durand et al. (2020) were also merged with our findings for further investigation of patterns in cumulative impacts from other stressors on SAR threatened by IS.

3.3 Data Analysis

The data emerging from our literature review was analyzed primarily through summary statistics using RStudio version 1.3.1073 (R Studio Team, 2020) running R statistical software (R Core Team, 2020).

4 Results

Initial screening flagged 176 SAR as being impacted by IS in British Columbia and/or the Pacific Ocean. Further examination of COSEWIC status assessments and SARA recovery strategies and management plans revealed that 92 of these species were impacted by at least one IS listed on the provincial Priority List. These 92 focal SAR represent a range of taxonomic groups including amphibians (n=5), arthropods (n=11), birds (n=9), freshwater fishes (n=16), terrestrial mammals (n=3), molluscs (n=9), reptiles (n=4), and vascular plants (n=35). The majority of focal SAR are listed by COSEWIC as endangered (n=56), while others are listed as threatened (n=19), as being of special concern (n=14), or as extirpated (n=3). All except 12 are also listed under SARA.

When considering all documented IS impacts for our 92 focal SAR (not just those of IS on the provincial Priority List), most SAR were impacted by more than one IS, with a total of **784 unique SAR-IS pairs encompassing 200 unique IS**. These 784 SAR-IS pairs were the subject of the systematic literature review, the findings of which are documented below.

4.1 Vectors of Introduction and Spread in Invasive Species Impacting SAR

Vectors of introduction were identified for 111 IS (Figure 1 – top panel). Slightly over half of these were assumed or known to be **introduced accidentally** (n=48) or through **self-dispersal** (n=15). The rest were intentionally introduced as **forage** for grazing cattle or other livestock, for **medicinal purposes**, for **consumption and /or recreation** (through fish stocking, etc.), as **ornamental plants or pets**, for **pest control** (e.g., invasive species management), or to assist with **seed collection** for the forestry industry.

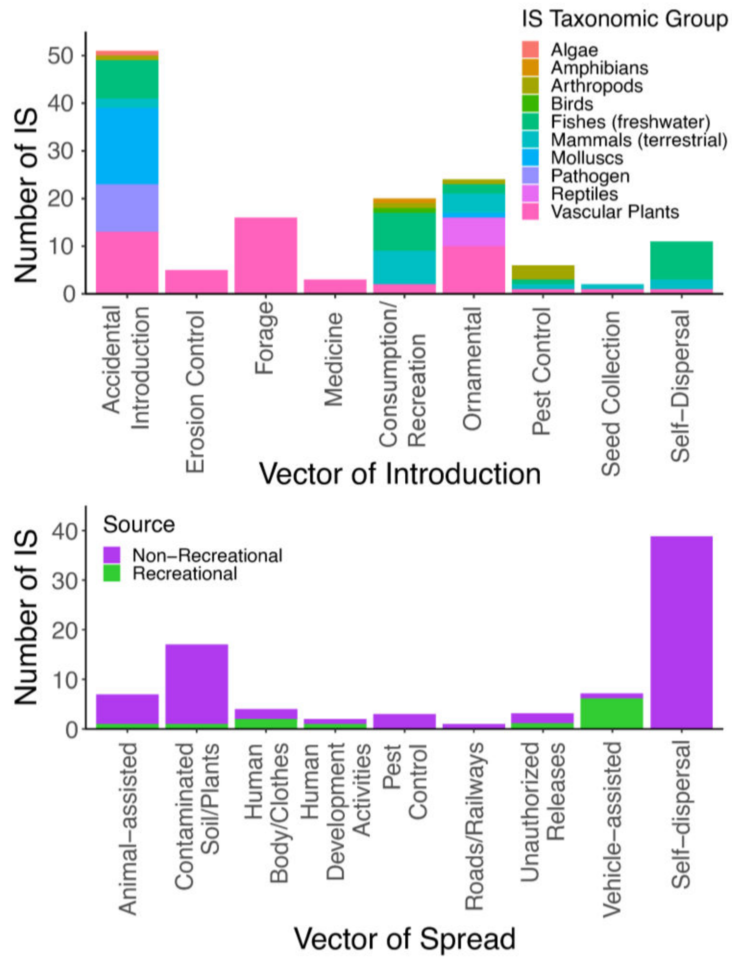

Figure 1. Top panel - vectors of introduction of IS, broken down by taxonomic group of IS. Bottom panel – vectors of spread of IS, broken down by recreational versus non-recreational sources. Note that one IS may be introduced or spread via more than one vector and therefore may be counted in more than one vector category.

Vectors of spread were identified for 65 IS (Figure 1 – lower panel). The vast majority spread by self-dispersal (n=39). IS also spread on **animals** (n=7), in **contaminated soil or plants** n=17), attached to **human clothing** or bodies (n=4), through habitat disturbance from **development activity** (n=2), for **pest control** (n=3), via **roads or railways** (n=1), via **unauthorized releases** of pets or displacements of wild animals (n=3), and via **vehicles** (n=7). Vectors of spread were sorted into recreational (i.e., activities potentially associated with tourism) and non-recreational (i.e., activities not likely to be associated with tourism) sources. Most of the vectors of spread do not appear to be directly associated with recreational sources. However, some recreational sources include off-road vehicles and trail bikes, recreational fishers' waders used in multiple water bodies, and transport of bait.

Many of the top twenty IS impacting SAR (see Section 4.6) were introduced over a hundred years ago as ornamentals (e.g., Scotch Broom, European Gorse), for forage (e.g., Sweet Vernalgrass, Common Velvetgrass) or for consumption and / or recreation (e.g., Largemouth and Smallmouth Bass, Yellow Perch, and American Bullfrog).

4.2 Mechanisms of Invasive Species Impacts on SAR

SARA documentation revealed eight mechanisms through which IS impact focal SAR (Figure 2):

1) **behavioural changes** (changes to regular habits or responses);
2) **biofouling** (accumulation of IS on SAR),
3) **collateral damage from invasive species management (ISM)** (to non-target species),

4) **competition** (interaction for the same resources),
5) **disease** (negative effects from fungi, parasites, viruses, etc.),
6) **genetic effects** (hybridization, gamete wastage, etc.),
7) **habitat alteration or degradation** (changes to the environment), and
8) **predation** (IS consuming animal or plant SAR).

Habitat alteration or degradation, competition, and predation are the primary mechanisms through which IS impact SAR. These mechanisms greatly affect plants, and to a lesser degree, fishes, molluscs, arthropods, and other taxonomic groups. The effects of other mechanisms were more constrained to specific taxa, with notable examples including genetic effects primarily impacting fishes, reptiles, and vascular plants (primarily through hybridization); disease affecting primarily amphibians (e.g., chytridiomycosis in salamanders, frogs, and toads), reptiles (e.g., Upper Respiratory Disease-like syndrome in turtles), and mammals (e.g., white-nose syndrome in bats), and collateral damage from ISM affecting primarily arthropods (e.g., through the non-target effects of pesticides on native arthropods). Nearly half of all SAR were affected by IS through more than one mechanism of action (range 1-5 mechanisms), and there were few cases where mechanism of impact was unidentified.

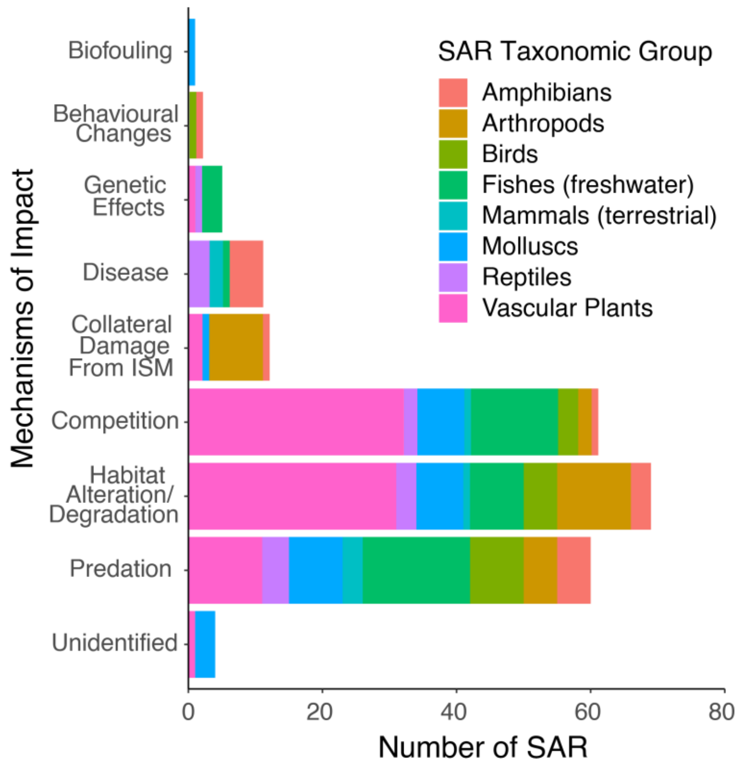

Figure 2. The mechanisms of IS impact on SAR, broken down by taxonomic group of the SAR. Note that one IS may have more than one mechanism of impact and therefore may be counted in multiple mechanism categories.

4.3 Magnitude of Invasive Species Impacts on SAR

Following alignment of the two types of threat calculators, ratings of the scope, severity, and timing of the threat (see definitions in Master et al. 2012 and ---

Appendix C) from invasive and problematic species were available for 67 of the focal SAR and total impact ratings were found for 69 species (Figure 3). The **scope** of the threat from invasive and problematic species, which refers to the proportion of the species that is expected to be impacted by the threat within 10 years, is pervasive for most SAR within most taxonomic groups.

Similarly, the **timing** of the threat is high for the majority of SAR within each taxonomic group, which means that the threat is continuing, as opposed to having taken place in the past (insignificant) or possibly occurring in the future (low – moderate). The **severity** of the threat, which is the level of damage to be expected from the threat within 10 years or three generations, varies in and across taxonomic groups. Some SAR in the taxonomic groups of amphibians, birds, fishes, and mammals have extreme severity ratings, indicating a level of damage that ranges from 71-100%. **Impact** is the degree to which the species is known or suspected of being threatened and is based on scope and severity ratings for present and future threats only. There are a wide range of calculated impacts in and across taxonomic groups, but many taxa are found to have a high proportion of SAR with 'high' or 'very high' overall impact ratings.

4.4 Geographic and Habitat Patterns of Invasive Species Impact

The distribution of IS impacts on SAR were mapped using ecoprovinces inhabited by each SAR affected as the unit of analysis (Figure 4 – panel A). There is a high concentration of SAR impacted by IS in the Georgia Depression. The Coast and Mountains, Southern Interior, and Southern Interior Mountains are home to the next highest concentrations of SAR-IS pairs. It should be noted that this analysis focuses on the distributions of the threatened SAR themselves, and does not reflect the geographic distribution of actual SAR-IS interactions as detailed information on IS distributions was not available at the time of analysis for comparison.

In terms of habitat types, the number of SAR impacted by IS is greatest in terrestrial habitats, followed by freshwater then marine habitats (Figure 4B). The small number of IS-SAR pairs in marine habitats should be interpreted with caution given that: (1) marine IS are not included on the provincial

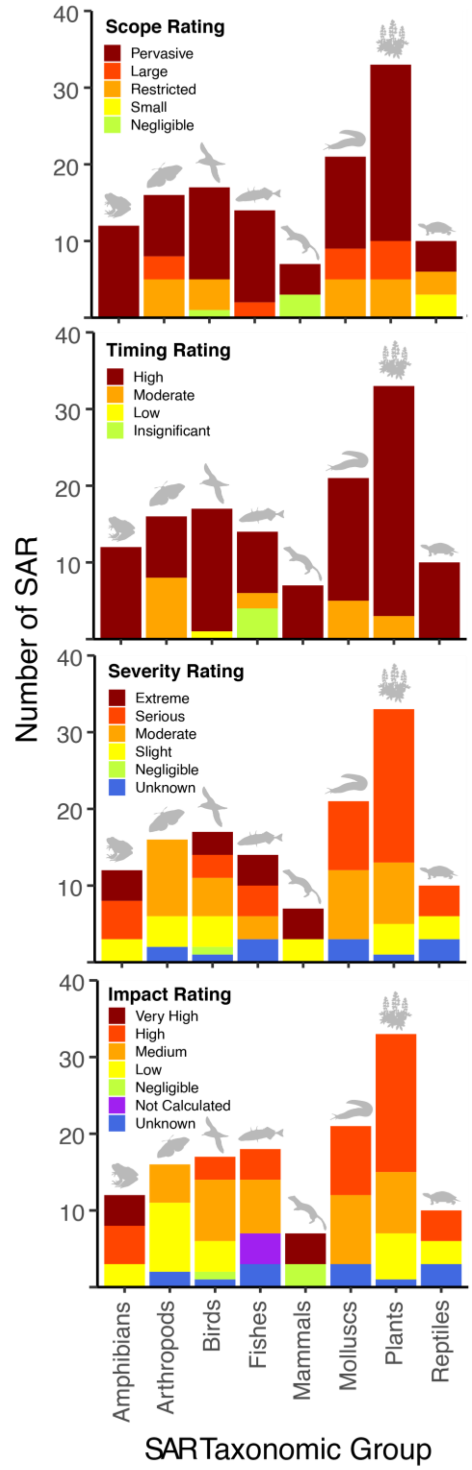

Figure 3. Impact, scope, severity, and timing of threats posed specifically by invasive and problematic species on the 92 focal SAR, broken down by taxonomic group of the SAR.

Priority List of IS (BC IMISWG 2020), (2) both freshwater and marine fish species are less likely to be listed under SARA because of economic considerations (Findlay et al. 2009, Mooers et al. 2007, Schultz et al. 2013), and (3) while it is known that many marine SAR are threatened by overexploitation, the impacts of marine invasive species on marine SAR in Canada's Pacific region remain poorly understood (Clarke Murray et al 2011, Howard et al. 2018).

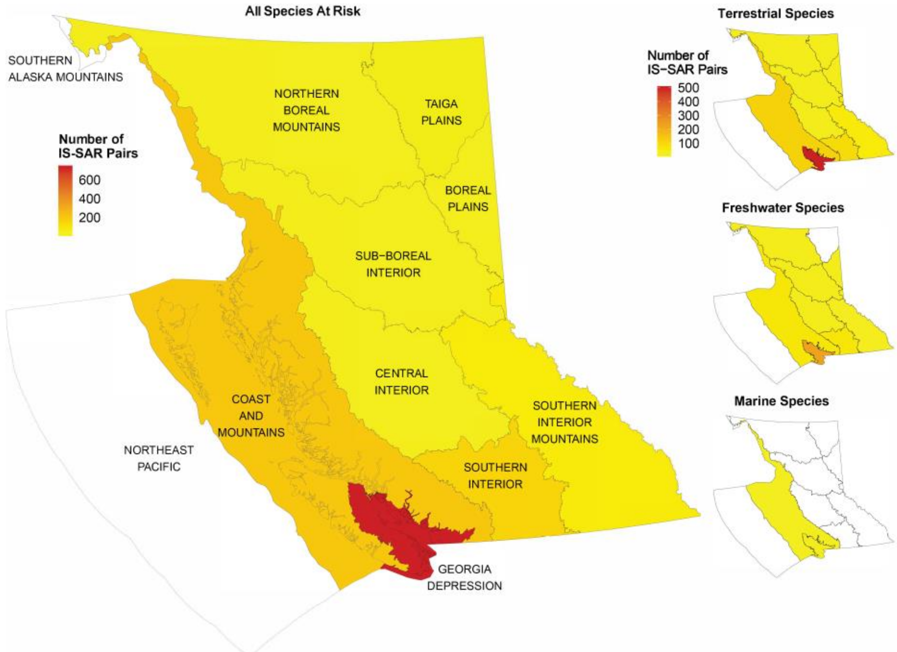

Figure 4. Main Panel (left) is a choropleth map of IS-SAR pairs per ecoprovince, with colour scale ranging from white (no IS-SAR pairs) to red (>600 IS-SAR pairs). Inset Panels (right) are three choropleth maps of IS-SAR pairs per ecoprovince, broken down by habitat type.

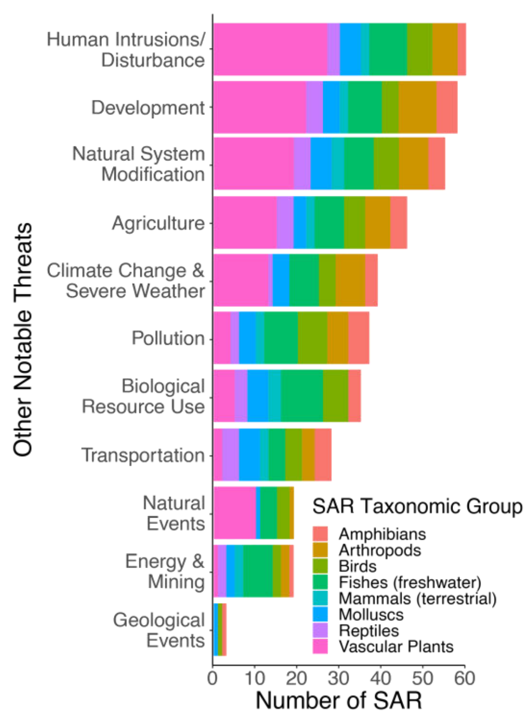

Figure 5. Other notable threats impacting SAR, as documented by Woo-Durand et al.

4.5 Other Threats to SAR Impacted by IS

(2020) and McCune et al. (2013) and broken down by taxonomic group of the SAR.

On average, the focal SAR were impacted by three other threat categories in addition to invasive and problematic species. Other notable threats impacting the focal SAR span all of the IUCN threat calculator's categories, however development and human intrusions or disturbances are the other threat categories most often faced by the focal SAR (Figure 5).

4.6 Management Priorities - Species Most Impacting and Most Impacted

Many of the IS that are most impacting SAR are plants (Figure **6** – panel A), including the top worst offender, which is Scotch Broom. Other major offender IS taxonomic groups include fishes, one amphibian (bullfrogs), and one mammal (domestic and feral cats). The majority of the top twenty SAR most impacted by IS are plants (Figure **6**B). Arthropods, a reptile, and a fish are also listed among the top twenty most impacted SAR. SAR tend to be impacted by IS in the same taxonomic group. Half of the topmost impacted SAR have impact ratings of 'very high' or 'high'. These ten species also have 'extreme' or 'serious' severity ratings. SAR tend to be most impacted by IS in the same taxonomic group.

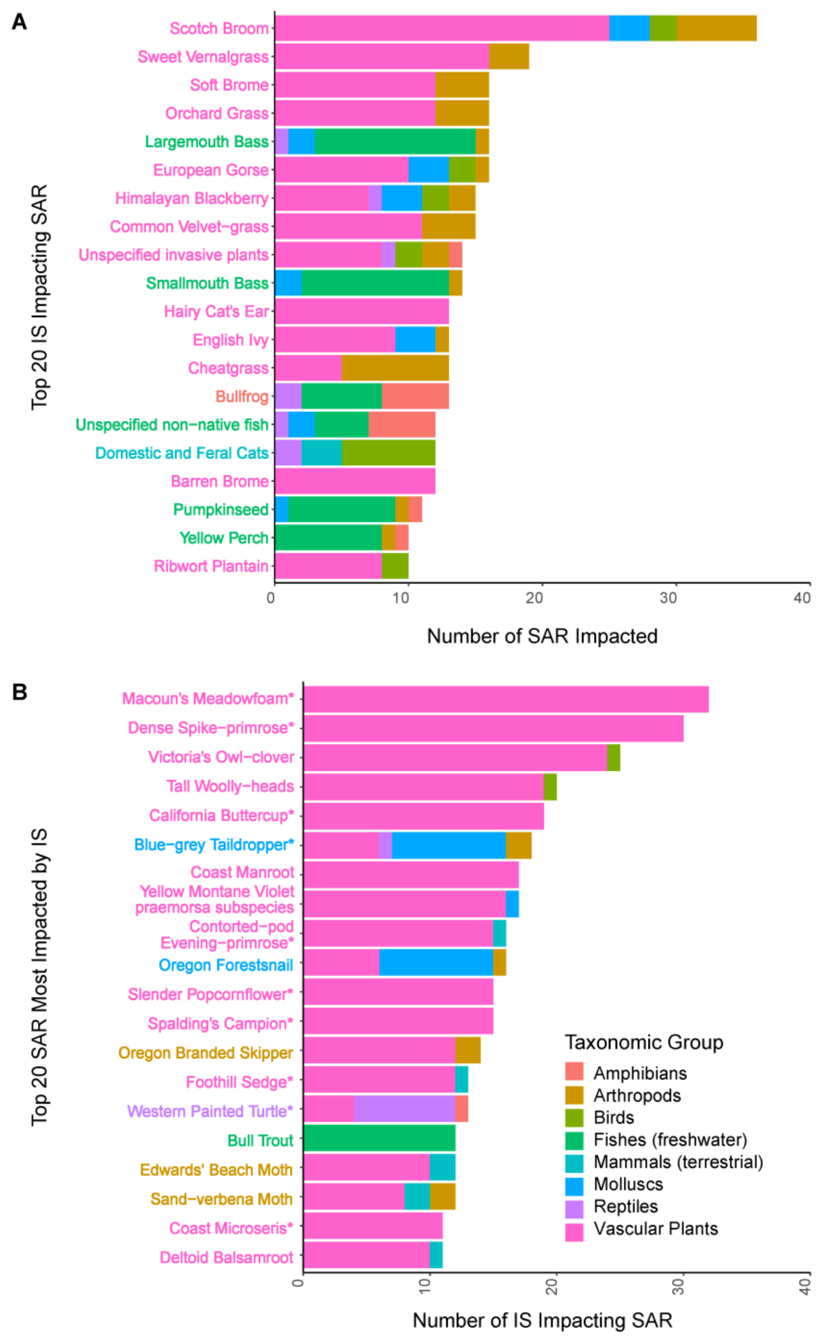

Figure 6. Panel A (top) shows the top 20 IS impacting SAR. The bars in panel A are colour-coded by the taxonomic group of the SAR, while the IS names are colour-coded by the taxonomic group of the IS. Panel B (bottom) shows the topmost impacted SAR. The bars in panel b are colour-coded by the taxonomic group of the IS, while the SAR names are colour-coded by the taxonomic group of the SAR. Asterisks (*) next to SAR names in panel B indicate species with an impact rating of "very high" or "high". Both panels are based on the number of unique IS-SAR impact pairs.

5 Discussion

This study reveals some notable patterns of impact of invasive species on species at risk in BC that will support more targeted invasive species research and management planning in the region.

Most Invasive Species of Concern Intentionally Introduced, Many Recreationally Spread

The majority of IS with identified vectors of introduction are the result of accidental introductions or self-dispersal, although there are some notable exceptions in this pattern for specific taxa – for example, nearly all freshwater fish included in our study were intentional introductions meant to support recreational fisheries. Given the drastic increases in IS introductions over the past century (IPBES 2019) and especially in the past fifty years (Seebens et al. 2017), it is surprising to find that many of the top IS impacting focal SAR have been in BC for over a century. That being said, some more recent introductions are also documented in our work. For instance, Canada Geese were introduced to new areas in the 1960s and 1970s and Snapping Turtles were first found on Vancouver Island in 2012. It is possible that these and other more recent invasions have not yet manifested their full impact on SAR, a recognized lag phenomenon known as "invasion debt" (Dunas et al. 2018), and that once more fully established, these species may figure more prominently among those IS impacting the most SAR.

Once introduced, IS continue to be spread, for the most part unintentionally, through a range of human activities, many of which are associated with the recreational sector (Anderson et al. 2015, Davis and Darling 2017, Huddart and Stott 2019). In this study, the vectors of invasive species spread in BC most closely associated with recreation include unauthorized intentional introduction of recreational species (e.g., illegal inter-basin transfers of sport fish), transportation on the human body or clothes (e.g., plant fragments or seeds adhering to boots or waders), human development (e.g., construction of recreational facilities), and especially vehicle-assisted dispersal (e.g., increased car or boat traffic to recreational hotspots). Greater understanding of these vectors of spread will be instrumental for informing targeted management interventions, particularly through public outreach in the recreational sector.

Invasive Species Impacts Manifest via Diverse Ecological Mechanisms

Once invasive species have arrived and established in a region where SAR are present, they may impact the populations of species at risk through a wide range of mechanisms and often through multiple mechanisms. Habitat degradation and alteration, competition, and predation are the primary mechanisms of impact, corroborating the outcomes of a similar exercise carried out for SAR listed under the US Endangered Species Act (Duenas et al. 2018). This is perhaps not a surprising for this study given that a large proportion (38%) of our focal SAR are plants with highly specific habitat requirements. Other mechanisms of impact were less common and often localized to a subset of taxa, however, many of these rarer mechanisms of impact are known to have disproportionate impacts on affected taxa. For example, the introduced fungal pathogen causing chytridiomycosis in amphibians has spread rapidly across BC (Govindarajulu et al. 2010 and 2017, Brunet et al. 2020) and the globe (Fisher and Garner 2020) with devastating effects on host populations that have in some cases led to extirpations. Similarly, the widespread hybridization of introduced brook trout with native bull trout leads to sterile offspring that contribute to wasted reproductive effort among remaining bull trout that exacerbate the competitive displacement of bull trout by brook trout (COSEWIC 2012b). A more distinct case encompasses impacts to species at risk caused by the collateral damage of invasive species control efforts rather than the invasive species themselves, most commonly manifesting as the non-target effects of pesticides applied to control invasive insect pests that also affect native arthropods (Buckley & Han 2014, see also Section 6.2 for a more detailed Case Study of this mechanism of impact). Clarifying our current understanding of the mechanisms of impact of IS on SAR will help to tailor management strategies to more effectively address impacts on SAR while also highlighting knowledge gaps that will prompt further research into the nature of IS impacts on SAR.

Threats Posed by Invasive Species to Species at Risk are Significant and Ongoing

The scope of threats from IS are pervasive and the timing is high (i.e., current and continuing) for a majority of focal SAR in all taxonomic groups. Although more variable, the severity and impact ratings of the threat from IS also tend to be pushing the upper ends of their respective spectrums within most taxonomic groups. Overall, the distribution of IS-SAR pairs roughly aligns with human population density in BC (Environmental Reporting BC 2018) and may therefore be reflective of the linkages between human activities contributing to IS propagation and spread and IS distributions. This is corroborated by the top other notable threats faced by these SAR, as documented in prior meta-analyses, which are development and human intrusions and disturbances. These findings align with the globally recognized drivers of invasion which are predominantly linked to human development, trade, and habitat degradation (IPBES 2019).

With regard to the Georgia Depression, the high concentration of IS impacts to SAR in that particular ecoprovince may also be partially explained by the number of focal SAR (n=9) that are closely associated with Garry-Oak ecosystems located in that region (PCA 2006). Garry Oak ecosystems are known to be threatened by invasive species, with over 80% of biomass in these ecosystems now consisting of invasive species (MacDougall & Turkington 2005). This finding is notable for the fact that IS impacts by multiple species that are concentrated in small, spatially-restricted pockets such as these represent opportunities for highly efficient management interventions that are likely to benefit multiple SAR in that same area. There may be other similar ecosystem clusters of IS-SAR impacts not uncovered in this study due to lack of information on IS impact locations in most SAR documentation.

Overall, the lists of top impacting IS and top impacted SAR are both dominated by plant species and in many cases, SAR seem to be impacted by IS in the same taxonomic group or another taxonomic group on which theirs closely depends (e.g., host plants for arthropods). It should also be noted that the literature we examined offered some counterexamples where IS were found to benefit SAR or local communities. For example, in Oregon, Taylor's Checkerspot butterfly is now dependent on the exotic larval host plant English plantain (*Plantago lanceolata*) for its survival (Severns 2008), while European Sheep Sorrel (*Rumex acetosella*) introduced during colonial times quickly became a staple for the Nuxalk people of British Columbia who benefited from the vitamin C content of its tart tasting leaves (Stopps et al. 2011). These more nuanced interactions between invasive and at-risk species are increasingly recognized, and some speculate that beneficial interactions may become more common in the future because they may be more likely than native species to persist and provide substitute ecosystem services in areas where land use and climate are rapidly changing (Schlaepfer et al. 2011). For such species, trade-offs between potential impacts and benefits of interventions must be carefully considered in management planning.

Value of Characterizing Impacts for Invasive Species Management Planning

By holistically examining the impacts that IS are having on SAR in BC, this study has unveiled valuable areas for future IS research, thereby contributing to regional IS management goals (ISCBC 2020, IMISWG 2014). The first step to enabling effective decision-making for IS management is to ensure that IS data are synthesized and accessible (Wallace et al. 2020).

Having done this, many valuable insights for building management strategies have emerged. First, the list of top SAR impacted by IS, when paired with data on the severity of impacts from IS and problematic species, presents an initial prioritization process for targeting interventions toward SAR most vulnerable to IS impacts. For example, Macoun's Meadowfoam is the SAR impacted by the most IS (n=32) and also happens to have an impact rating of 'high' and a severity rating of 'serious'. This suggests that management of IS impacting Macoun's Meadowfoam may be of high importance and, in addition, could have rollover benefits for other species also impacted by the same IS in the same area. Similarly, the list of top IS impacting SAR can be used for prioritizing targeted IS interventions that will assist the widest range of SAR. For example, Scotch Broom is the IS that impacts the most focal SAR (n=36) and therefore, management efforts targeting Scotch Broom could have broad conservation benefits for many SAR and potentially, other native species that are not yet at risk. Information on the mechanisms of IS impact can also guide the selection of the most effective management interventions – for example, impacts known to be caused by collateral damage from the use of pesticides might be mitigated by switching to more targeted biocontrol measures, while impacts arising from disease transmission may be addressed by reducing contact with possible disease vectors. Finally, information about vectors of introduction and spread allow for targeted public outreach campaigns and management strategies for specific sectors (e.g., Marsh et al. 2021). For example, our study found that IS are frequently introduced as ornamental plants or in the soil of non-native plants. Contaminated soil and/or plants are also a vector of spread for many IS. Thus, a campaign to raise awareness of gardeners about unintentional spread of IS may be warranted.

Resources for managing IS are often insufficient for the number of potential actions that could be undertaken, so management actions must be prioritized in such a way to maximize benefits (Courtois et al. 2018, Januchowski-Hartley et al. 2011). This process generally involves conducting cost-benefit analyses, assessing the feasibility of actions, and evaluating trade-offs between different options. The findings of this report can also feed new information into these existing prioritization tools. For example, an IS control that is considered cost prohibitive may be rated differently once its cost-benefit analysis considers the number of SAR that could benefit from the action.

In considering future research and management approaches based on the findings of this review, some caveats must be noted. First, this review is biased toward terrestrial and freshwater IS-SAR interactions. This is in part because the Provincial IS Priority List does not include any marine species, but also because interactions between marine IS and SAR are more difficult to study and the extent and nature of their impacts are not yet well understood (Clarke Murray et al 2011, Howard et al. 2018).

Another caveat to bear in mind is the non-restrictive definition of invasive that is used in this review. Some of the IS documented here may not be considered invasive based on other definitions. For example, some of these IS are provincially native but regionally invasive. Canada Geese are likely native to BC, but were uncommon until the 1960s and 1970s, when the Canadian Wildlife Service introduced geese to new areas in hopes of improving wildlife viewing and hunting opportunities (Capital

Regional District 2012). Readers should refer to Section 6.3 for a Case Study on this topic.

Promising Avenues for Future Work

This review has revealed several promising avenues of future research that build on the foundation of our work. First, it may be worthwhile to devote additional resources to filling remaining gaps in our data set, including gaps on vectors of introduction and spread, key locations of IS-SAR interactions, and IS impacts to SAR in marine environments, to the extent that this information is available.

Following this, a logical next step for BC would be to conduct a spatially explicit analysis to look at actual distributional overlaps between IS and the SAR that they impact, where spatial information for these species is available. SAR occurrence data are frequently provided on maps in SARA documentation and therefore raw occurrence data are likely available from the Federal agencies that assessed these species. In addition, the BC Government's Conservation Data Centre holds further spatial information for SAR. Information on the distribution of IS may be available through the province's aquatic and terrestrial fauna invasive species programs, the Invasive Alien Plant Program, or other provincial efforts. Further information may soon be available through the forthcoming invasive species data system that is being developed by the BC Government. Alternatively, a broader approach that addresses a suite of species or a landscape using a habitat suitability analysis could also be considered (e.g., as in Allen et al. 2006, 2015). This type of analysis would help to identify and triage localized areas of high impacts to SAR that would help to efficiently allocate limited management resources and tailor management interventions to regionally-specific mechanisms of dispersal. Such an analysis might also help to shed light on where IS-SAR interactions intersect with areas of significance to Indigenous peoples and lead to more targeted community-based management efforts of the kind already being implemented in some parts of the province (ISCBC 2019).

Another pressing area of future research would be to better understand the management implications of invasive species threats against the backdrop of accelerating global climate change. Climate change is a key threat to biodiversity in itself and when paired with the threats posed by IS presents even greater challenges (Mainka & Howard 2010). Climate change is expected to cause range shifts of both native and non-native species and accelerate the introduction and spread of IS (Hellman et al. 2008, Walther 2011, IUCN 2021). In addition, climate change is also likely to alter the impact of existing IS and the effectiveness of current control strategies (Hellman et al. 2008). In some cases, IS may also exacerbate climate change by reducing the climate resilience of natural habitats (e.g., by providing less shade than native species or contributing to more severe fire events) (IUCN 2021). As a result of these potentially synergistic effects to biodiversity, there is an urgent need for targeted research that will allow these threats to be more explicitly incorporated into management strategies for both IS and SAR (Mainka & Howard 2010, Beaury et al. 2020). For example, the use of assisted colonization may help SAR to keep pace with the more rapid climate-induced range shifts of invasive species or relocate these species to climate refugia where they will be more resilient to the effects of invasions (Gallagher et al. 2014). However, more work is needed to better understand adaptation strategies for reducing the climate change impacts of invasive species on species at risk.

Finally, there is great potential for using the approach developed here to expand this work to a national scale to help inform management planning on other regions of Canada, where invasive species post similar risks to many other species at risk not examined in this study. Establishing a national baseline characterizing the impacts of invasive species on species at risk would not only contribute to more effective regional management planning (e.g., by both helping to tailor invasive species management strategies to specific contexts and also unlocking access to funding earmarked for SAR conservation), but would also serve to inform national recovery planning for species at risk as well as a more comprehensive national response strategy for invasive species.

In these and other ways, leveraging available information to craft coordinated and complementary management strategies for invasive species and the species at risk with which they interact is expected to yield more efficient and effective conservation outcomes than otherwise possible.

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6 Case Studies of Invasive Species Impacts

The case studies in this section expand on some central themes emerging from our synthesis work and provide a place to add more context to these topics than possible in our more quantitative analysis. In addition to the future work highlighted in the discussion section of this report, more research focused on any of the thematic areas described here would represent a valuable contribution to this applied research space.

6.1 Case Study: BC's "Most Wanted"

Scotch Broom in bloom.
Photo Credit: "Yellow Scotch Broom" by tdlucas5000 is licensed under CC BY-SA 2.0

BC's 'most wanted' IS are those that impact a disproportionate number of SAR. Thirteen of the top 20 most wanted IS are plants and the remainder are species of fish, one amphibian, and one terrestrial mammal.

The top offender, Scotch Broom, is a shrub from the pea family (Fabaceae) (Dennehy et al. 2011) and is often associated with a suite of other invasive shrubs, grasses, and forbs, including the second, third, and fourth most wanted IS: Sweet Vernalgrass, Soft Brome, and Orchard Grass, respectively. In this review, it is documented as a threat to 36 focal SAR, which are primarily plants, but also arthropods, molluscs, and birds.

Scotch Broom was introduced to BC as an ornamental garden plant sometime in the late 1800s and has likely spread both intentionally and unintentionally since then (Lee 2010). It produces thousands of seeds per year and these can remain viable for up to thirty years. The shrub thrives in disturbed areas (along roadsides, in logged areas, cleared land) and will spread from these sites to grasslands and pastures. In BC, it primarily threatens Garry Oak and arbutus ecosystems, as well as commercial forest sites planted with Douglas Fir.

Scotch Broom is currently being managed at various SAR locations in BC. On Vancouver Island, Scotch Broom removal is happening at HMCS Quadra 19 Wing Comox as part of a protection plan for SAR and their habitat (COSEWIC 2013). Nearby at Rocky Point, Scotch Broom has been targeted in ongoing removal efforts since 2002 (COSEWIC 2010a). On the Trial Islands, 95% of the Scotch Broom biomass was removed through a decade of work (2002-2012) (COSEWIC 2015). The species' tolerance of disturbed areas as well as its prolific seed production make it a challenging invasive to combat.

6.2 Case Study: Role of Collateral Damage from ISM in Impacts to SAR

In addition to the threat from IS themselves, various SAR also face potential collateral damage from IS management techniques. For this reason and others, prevention of IS is a much better approach than attempting to control IS once they are introduced and, if IS control is necessary, it is crucial to consider the potential negative offsets before implementation (Buckley & Han 2014).

Caterpillar of the European Gypsy Moth.
Photo Credit: "Gypsy moth caterpillar (Lymantria dispar)" by NatureFreak07 is licensed under CC BY 2.0.

The European Gypsy Moth is an invasive moth that defoliates trees. The species first appeared in BC in 1978 and since then, numerous eradication battles have been fought after repeated introductions (Nealis 2009). Six arthropod SAR are threatened by potential control efforts for European Gypsy Moths. The most immediate threat is a pesticide control called *Bacillus thuringiensis* var. kurstaki (Btk). Btk is a spray consisting of spores of pathogenic bacteria that kill target and non-target arthropods (EC 2012). Btk has been applied in BC since the 1980s in response to European Gypsy Moth detections (Nealis 2009). Another biological control for European Gypsy Moths is Tachinid flies. These introduced parasitic flies are known to have adverse impacts to all moth species (EC 2012). Although these species have only been introduced to the eastern United States and Canada, they still represent a major threat to BC's arthropods because they could disperse westward naturally or intentionally through biological control efforts.

Other IS Management techniques that have potential or known impacts to SAR include:

- Use of the beetle *Chrysolina hyperici*, which was introduced in the 1950s as a biocontrol for invasive St. John's Wort (Williams 1984) and may have impacts to plants living near St. John's Wort, such as Dwarf Hesperochiron and Columbia Quillwort (COSEWIC 2019b, 2019c). The impacts of Chrysolina hyperici are unknown.
- Rototilling lake substrate to control invasive Eurasian Milfoil. Informal research suggests that this activity may have negative direct or indirect negative effects on bottom-dwelling animals, particularly the Rocky Mountain Ridged Mussel and, to a lesser degree, the Olive Clubtail (COSEWIC 2010b, COSEWIC 2011).
- Use of herbicides to control noxious weeds, which may have an impact on nearby SAR plants such as Showy Phlox (COSEWIC 2004a).

While biological control efforts must proceed with caution to avoid unintended consequences to native species, evidence is emerging to suggest that these programs can successfully achieve their intentions without causing excessive damage to non-target species (Gibson et al. 2019, Lindenmayer et al. 2017, Myers et al. 2016). A most robust approach to biological control efforts may be through a trophic food web framework, in which the effects of removing one invasive species are pre-emptively examined in the context of other co-occurring native and invasive species (Ballari et al. 2016). Physiological research (Lennox et al. 2015) and gene drive technology (Moro et al. 2018) may also present new options or techniques for controlling invasive animals.

6.3 Case Study: Localized Invasions of Native Species

Not all the IS documented in this review originate from other countries or even other provinces. There is growing recognition that invasive species can also be native species with increasing populations and broadening distributions (Carey et al. 2012, Valéry et al. 2009).

Haida Gwaii has been subject to many introductions of species that are native to other parts of BC. For example, Sitka Black-tailed Deer are native to BC, but were introduced repeatedly to Haida Gwaii between 1878 and 1925 in attempts to establish a new game species (Gaston et al. 2008). Similarly, the Common Raccoon, also native to BC, was introduced in the 1940s by the BC Game Commission to expand the local fur trade (Harfenist et al. 1999). Both the species have spread to new islands by swimming. Also in the 1940s, the BC Forest Service introduced red squirrels to Haida Gwaii to assist with collection of Sitka Spruce seeds (Gaston et al. 2008).

Outside of Haida Gwaii, Canada Geese are another example of a native species that is considered invasive in some contexts. This is because the species was introduced to new areas by the Canadian Wildlife Service and partnering organizations in the 1960s and 1970s in hopes of establishing new wildlife viewing and hunting opportunities (Capital Regional District 2012). Introduced geese became non-migratory populations because they were not imprinted to a migration route.

Sitka Black-tailed Deer on Haida Gwaii.
Photo Credit: "057A1387.jpg" by Murray Foubister is licensed under CC

In addition to intentional expansions of native species distributions, range changes of native species are likely to continue without human assistance due to climate change (Walther 2011, Hellman et al. 2008). This will further complicate distinctions between native and non-native species. Native species with expanding ranges due to climate should not necessarily be considered invasive (Urban 2020), however distinguishing between climate-tracking species and invasive species is likely to be challenging as climate change progresses.

6.4 Case Study: Invasions Resulting in Extirpations of SAR

Unfortunately, the threat from IS to BC SAR has been definitively shown in some cases. These cases are reflective of the growing number of global extirpations and extinctions caused by IS (Blackburn et al. 2019, IPBES 2019) and serve as cautionary tales of the potential fate of other SAR if IS threats are not abated.

Two notable cases of IS causing extinction come from the endemic stickleback species pairs in the Pacific Islands Ecological Area. The Hadley Lake Stickleback pairs became extinct in the 1990s due to the unauthorized introduction of Brown Bullhead, which likely predated stickleback eggs (Dextrase and Mandrak 2006). More recently, the Enos Lake stickleback pairs have undergone introgressive hybridization and collapsed into a hybrid population, likely as a result of the introduction of the American Signal Crayfish (Velema et al. 2012). Both these IS-SAR interactions serve as warning of the magnitude of the threat from IS to remaining stickleback pairs, including the Paxton Lake and Vananda Creek stickleback pairs from our focal list of SAR (DFO 2016).

Apart from total extirpations or species collapses, IS are also suspected to have played a role in local extirpations. This has been documented for Macoun's Meadowfoam (PCA 2013) and Victoria's Owl Clover (ECCC 2017), which are the first and third most impacted SAR in our review, respectively. In addition, some colonies of Cassin's Auklet and Ancient Murrelet in Haida Gwaii have been extirpated by rats (Regehr et al. 2007, Golumia et al. 2008).

6.5 Case Study: Invasive Threats to SAR Important to Indigenous Peoples

Ancient Murrelet, a predominant traditional food species for Haida.

Photo Credit: "File:Ancient Murrelet - Semiahmoo Spit.jpg" by Eric Ellingson is licensed under CC BY 2.0.

Many plants and animal species, including SAR, hold special meaning for Indigenous peoples and IS are documented to have devastating impacts to culturally important species (ISCBC 2019, Reo et al. 2017). Unfortunately, the significance of SAR to Indigenous groups is not well documented in western literature. In Canada, this is in part due to expungement from SARA documentation to respect the intellectual and cultural property rights of Indigenous peoples as owners of this knowledge. While we recognize the rights of Indigenous peoples to protect this information, we also acknowledge the importance of considering SAR's value to Indigenous groups as part of gaining a holistic understanding of their importance.

On Haida Gwaii, Cassin's Auklet and Ancient Murrelet were predominant parts of Haida diet as both meat and eggs (COSEWIC 2014). Cassin's Auklets were particularly important sources of sustenance because they were available for a longer season than Ancient Murrelet. In fact, remains of Cassin's Auklets account for 39% of all bird remains found in archaeological sites on Haida Gwaii. Though few details are known, the Northern Saw-whet Owls also appear to be significant to Aboriginal groups on Haida Gwaii, because Haida from Cumshewa are known as the ‘Saw-whet Owl People” (COSEWIC 2017). Similarly, while knowledge about the significant of Haida Ermine is sparse, they are likely significant given their presence on many crests within the Raven and Eagle Clans (COSEWIC 2015a). In terms of plants, the Silky Beach Pea is an example of an understory vegetation that was used for sustenance by Haida. Silky Beach Pod roots were roasted, pit-cooked, or dried in cakes for preservation (Kuhnlein and Turner 1996).

Outside of Haida Gwaii, SAR are also valued by Indigenous peoples for various cultural, nutritional, medicinal, spiritual, and material purposes. For example, in the Interior, Rocky Mountain Ridged Mussels were likely used for food, tools, and ornaments (COSEWIC 2010b). In the Fraser Valley and coastal BC, White Sturgeon provided food and clothing to Aboriginal Peoples, and also appear in many stories and legends (COSEWIC 2012c). Similarly, Mountain Sucker were sources of sustenance and subjects of myths for Aboriginal Peoples in the Okanagan (Bouchard and Kennedy Research Consultants 2005).

Indigenous Peoples are not only documented users of SAR, but were also once stewards for many of these species. Before being banned in the 1920s, coastal First Nations’ land management practices involved controlled burns to increase production of Camassia species and to improve forage for ungulates (COSEWIC 2009a, Hoffman et al. 2019). SARA documentation suggests that these burns likely improved habitat suitability for many plant species including Deltoid Balsamroot (COSEWIC 2009b), Victoria’s Owl-clover (COSEWIC 2010c), Macoun’s Meadowfoam (COSEWIC 2004b), Dense-flowered Lupine (COSEWIC 2005), Prairie Lupine (COSEWIC 2009a), Coast Microseris (COSEWIC 2006), Slender Popcornflower (COSEWIC 2008), Tall Woolly-heads (COSEWIC 2018), California Buttercup (COSEWIC 2008a), Bear’s-foot Sanicle (COSEWIC 2015b), Lindley’s False Silverpuffs (COSEWIC 2008b), and Yellow Montane Violet praemorsa subspecies (COSEWIC 2007). These burns also likely improved habitat for some animal focal SAR, such as the Streaked Horned Lark (COSEWIC 2018) and the Oregon Branded Skipper (COSEWIC 2013).

Beyond understanding the impacts of IS to SAR of importance to Indigenous peoples, there is also a need to consider the cultural context of invasive species management occurring on Indigenous lands. This is especially relevant considering that Indigenous peoples are often the first responders to invasive species threats occurring in their traditional territories and represent critical partners in range-wide control efforts for invasive species (Reo et al. 2017, ISCBC 2019). For example, management efforts must consider both the impacts of the invasive species as well as potential collateral damage from management interventions to native species and cultural practices (e.g., harvest for food or medicine) of significance to local Indigenous communities. Planning and implementing such programs in collaboration with Indigenous communities though a co-management lens allows the benefits accruing from these initiatives to extend beyond the conservation of biodiversity to become culturally meaningful as well (Bellis et al. 2019).

7 References

Note that this reference list includes only those publications cited in this report, whereas references consulted for the literature review are captured separately within the project tracking spreadsheet containing the final data set (available from **Appendix A**).

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Appendix A: Project Data Set

The complete project dataset is available as an Excel spreadsheet from the following direct download DropBox link:

https://www.dropbox.com/scl/fi/8gauyph9ysdf8wegkyygh/ISCBC_TrackingTable_20210329_ForDistribution.xlsx?dl=0&rlkey=xvrxwbp0uub1b2xl48xm6kz7u

This dataset is a valuable product of this work in and of itself and will be most useful to managers and researchers interested in better understanding and mitigating impacts or of on specific species.

The following list describes the contents of each sheet in this file (also in the file itself):

- **TrackingTable:** This sheet contains the primary data on impacts to each SAR (rows) impacted by at least one IS on the BC Priority List of Invasive Species (core columns). Additional columns in this spreadsheet track other categorical variables describing the interactions between each IS-SAR pair, including vector of introduction, mechanism of impact, etc.
- **Invasive Species:** This sheet consolidates information for each of the IS presented on the first sheet, and provides a place to store IS-specific information (e.g., BC Priority List designation, taxonomic group, vectors of introduction and spread) not specific to a given SAR interaction.
- **Other Notable Threats**: This sheet contains raw data extracted from two prior studies on impacts to SAR in Canada (McCune et al. 2013, Woo-Durand et al. 2020) and merged here for an analysis of other types of threats commonly affecting SAR that are impacted by IS.
- **Variable Overview**: This sheet provides definitions and rationale for some of the variables (columns) in the TrackingTable sheet.
- **References**: This sheet provides all the references cited in short form on other sheets.
- **Dropdown Lists:** This sheet provides the drop-down lists used for data validation on the TrackingTable sheet.

Appendix B: Project Analysis R Code

This appendix reproduces the core R Code used for data analysis and creation of the building blocks of figures presented in this report. In addition to the code text below, the original R file is available from the following direct-download DropBox link:

https://www.dropbox.com/s/mu7obxcz2yrpy1b/InvasivesAnalysis-ForDistribution.R?dl=0

```
#This file contains the code used for analysis from a systematic literature review on the impacts of invasive species on species at risk in British Columbia.

#Set working directory
setwd()
Full<- read.xlsx("./ISCBC_TrackingTable_20210217_analysis.xlsx", detectDates = TRUE)
Full1<-Full[-c(1:3),]
names(Full1)[names(Full1)== "Mechanism(s).of.Threat/Impact"]<-"Mechanism of Threat"
names(Full1)[names(Full1)== "Magnitude.of.Threat./.Impact"]<-"Magnitude of Threat"
names(Full1)[names(Full1)== "Confidence.in.Magnitude.of.Threat./.Impact"]<-"Confidence in Magnitude"
names(Full1)[names(Full1)== "SARA.Strategies.&.Conservation.Measures.(Invasive.Species.Focus)"]<-
"Strategies"
names(Full1)[names(Full1)== "Other.Information.relating.to.Indigenous.Peoples.&.the.SAR"]<-"Other
Indigenous Information"
names(Full1)[names(Full1)== "Other.Notable.Threats.***"]<-"Other Notable Threats"
names(Full1)[names(Full1)== "Recovery.Strategy.Available?"]<-"Recovery.Strategy.Available"
names(Full1)[names(Full1)== "_______________________________________"]<-"Nothing"

Full2<-subset(Full1, select=-c(Habitat.Notes, Summary.of.Problematic.Native.Species.Impacts,
                               Summary.of.Invasive.Species.Impacts,
Geographic.Areas.of.Invasive.Species.Threat,
                               Geographic.Areas.of.Invasive.Species.Threat,
                               Vector.of.Introduction,
                               Year.of.introduction,
                               Notable.Information.Gaps,
                               Importance.to.Indigenous.Peoples,
                               Supporting.References,
                               NOTES, Recovery.Strategy.Available, Strategies, `Other Indigenous
Information`, `Other Notable Threats`,
                               `Confidence in Magnitude`, `Magnitude of Threat`, `Mechanism of
Threat`, Nothing))

#Separate RefID

Full3<-Full2 %>% separate(Ref.ID, c("RefNum", "RefLet"), "-", remove=FALSE)

#Start of Analysis

################# Figure 6 Top IS and Top SAR ##########################

InvasivesMatrix<- Full3[c(2,4,5,8:20,25,26:227)]
InvasivesMatrix2<-gather(InvasivesMatrix, key = "Invasive", value = "Presence",-c(RefNum,
Taxonomic.Group, `Species.at.Risk.(SAR).Common.Name`, Georgia.Depression, Coasts.and.Mountains,
Southern.Interior, Southern.Interior.Mountains, Central.Interior, Terrestrial, Freshwater, Marine,
`Sub-Boreal.Interior`, Boreal.Plains, Taiga.Plains, Northern.Boreal.Mountains, Northeast.Coast,
X24))
InvasivesMatrix2<-InvasivesMatrix2 %>% drop_na(Presence) #this is the total number of impacts
#But we want to show the total number of SAR impacted
InvasivesMatrix3<-InvasivesMatrix2 %>% distinct(RefNum, Invasive, .keep_all = TRUE) #This is
starting point for many calculations below

#Which invasive species are of greatest threat to SAR in BC?
#Who are the 'worst offenders'?
#Do some invasive species have broader or more disproportionate impacts across SAR than others?
InvasivesMatrix4<-InvasivesMatrix3 %>% count(Invasive)
InvasivesMatrix5<-InvasivesMatrix4 %>% arrange(desc(n))
InvasivesMatrix5<-InvasivesMatrix5[c(1:20),]
InvasivesMatrix5$Invasives2<- gsub("[.]", " ", InvasivesMatrix5$Invasive)
InvasivesMatrix3.5<-InvasivesMatrix3
```

```
InvasivesMatrix3.5<-InvasivesMatrix3.5%>% group_by(Invasive, Taxonomic.Group) %>% tally()
InvasivesMatrix3.5.5<-subset(InvasivesMatrix3.5, Invasive %in% InvasivesMatrix5$Invasive)
InvasivesMatrix3.5.5$Invasive2<-gsub("[.]", " ", InvasivesMatrix3.5.5$Invasive)
InvasivesMatrix3.5.5$Invasive2<-factor(InvasivesMatrix3.5.5$Invasive2,
                                       levels=c("Ribwort Plantain", "Yellow Perch", "Pumpkinseed",
                                       "Barren Brome", "Domestic and Feral Cats", "Unspecified non-
                                       native fish", "Bullfrog", "Cheatgrass", "English Ivy", "Hairy
                                       Cat's Ear", "Smallmouth Bass", "Unspecified invasive plants",
                                       "Common Velvet-grass", "Himalayan Blackberry", "European
                                       Gorse", "Largemouth Bass", "Orchard Grass", "Soft Brome",
                                       "Sweet Vernalgrass", "Scotch Broom"))
```

#FIGURE 6A - Top worst IS offenders

```
TopIS<-ggplot(data=InvasivesMatrix3.5.5, aes (x=Invasive2, y=n, fill=Taxonomic.Group))+
       geom_bar(stat="identity")+   theme_classic()+ scale_y_continuous(expand = c(0,0),
       limits=c(0,40))+ theme(axis.text.x = element_text(vjust = 0, hjust=0.95), legend.position =
       c(0.75,0.25), text=element_text(size=18)) + xlab("\nTop 20 IS Impacting SAR\n") +
       ylab("\nNumber of SAR Impacted\n")+   coord_flip()

#Which SAR on our list are most impacted by IS?
InvasivesTaxa<- read.xlsx("./Invasives_Taxa.xlsx") # Load taxonomic assignments for IS
InvasivesTaxa$Invasive <- trimws(InvasivesTaxa$Invasive.Species, which = c("both")) # Trim extra
spaces at end of names
InvasivesTaxa$Invasive <- gsub(' ','.',InvasivesTaxa$Invasive) #add period separators to match
Invasive.Specie column as key
InvasivesMatrix2.5 <- merge(InvasivesMatrix2,InvasivesTaxa, by="Invasive") # Merge to long data
format by common name to assign taxa
InvasivesMatrix2.5 <- InvasivesMatrix2.5[,c(2:4,20:22)]
names(InvasivesMatrix2.5)[3] <- "Species.at.Risk.Common.Name" #Remove brackets for working with this
variable name
as.factor(InvasivesMatrix2.5.2)
str(InvasivesMatrix2.5.2)

InvasivesMatrixCalc<- Full3[c(2,4,5,8:20,25,26:227,245:248)]
InvasivesMatrixCalc2<-gather(InvasivesMatrixCalc, key = "Invasive", value = "Presence",-c(RefNum,
Taxonomic.Group, `Species.at.Risk.(SAR).Common.Name`, Georgia.Depression, Coasts.and.Mountains,
Southern.Interior, Southern.Interior.Mountains, Central.Interior, Terrestrial, Freshwater, Marine,
`Sub-Boreal.Interior`, Boreal.Plains, Taiga.Plains, Northern.Boreal.Mountains, Northeast.Coast, X24,
Impact, Scope, Severity, Timing))
InvasivesMatrixCalc2<-InvasivesMatrixCalc2 %>% drop_na(Presence) #this is the total number of
impacts
#But we want to show the total number of SAR impacted
InvasivesMatrixCalc3<-InvasivesMatrixCalc2 %>% distinct(RefNum, Invasive, .keep_all = TRUE) #This is
starting point for many calculations below

#But we want to show the total number of IS by unique SAR - remove duplicate rows (reflect
differences in variables not used here)
InvasivesMatrix2.5.2<-InvasivesMatrix2.5 %>% distinct(RefNum, Invasive.Species, .keep_all = TRUE)
InvasivesMatrix2.5.3 <-InvasivesMatrix2.5.2 %>%
group_by(Species.at.Risk.Common.Name,Invasive.Taxonomic.Group) %>% tally()
InvasivesMatrix2.5.3_sort <-as.data.frame(InvasivesMatrix2.5.3 %>% arrange(desc(n)))

#Now get names of Top20 for subsetting the plot but still allowing stacked bars by IS Taxa
InvasivesMatrix2.5.3_topSAR <-InvasivesMatrix2.5.2 %>% group_by(Species.at.Risk.Common.Name) %>%
tally()
InvasivesMatrix2.5.3_topSAR_sort <-as.data.frame(InvasivesMatrix2.5.3_topSAR %>% arrange(desc(n)))
InvasivesMatrix2.5.3_top20<-
as.vector(InvasivesMatrix2.5.3_topSAR_sort$Species.at.Risk.Common.Name[c(1:20)])
```

#FIGURE 6b - Bar Plot - TOP 20 SPECIES with "very high" or "high impact" marked by asterisk

```
  #(corresponds to top species with "extreme" or "serious" severity rating)
TopSAR<-ggplot(InvasivesMatrix2.5.3_sort, aes(x = reorder(Species.at.Risk.Common.Name, -n), y = n,
fill = Invasive.Taxonomic.Group)) +  # Create stacked bar chart
    geom_bar(stat = "identity")+
    theme_classic()+
    scale_y_continuous(expand = c(0,0), limits=c(0,40)) + theme(axis.text.x = element_text(vjust =
0, angle=90, hjust=0.95),
    legend.position = c(0.75,0.25), text=element_text(size=16))+
    scale_x_discrete(limits=rev(InvasivesMatrix2.5.3_top20),
    labels=c("Deltoid Balsamroot", "Coast Microseris*", "Sand-verbena Moth","Edwards' Beach Moth",
"Bull Trout", "Western Painted Turtle*","Foothill Sedge*", "Oregon Branded Skipper", "Spalding's
Campion*","Slender Popcornflower*", "Oregon Forestsnail","Contorted-pod Evening-primrose*", "Yellow
Montane Violet\npraemorsa subspecies","Coast Manroot", "Blue-grey Taildropper*", "California
Buttercup*","Tall Woolly-heads", "Victoria's Owl-clover", "Dense Spike-primrose*","Macoun's
```

```
Meadowfoam*")) + # Sets limits of bars shown based on list of top 20 names
    coord_flip() + #use rev in line above only with coord flip
    xlab("\nTop 20 SAR Most Impacted by IS") + ylab("Number of IS Impacting SAR\n")+
    labs(fill="Invasive Taxonomic Group")

#Figure 6 compiled
ggarrange(TopIS, TopSAR, ncol=1, nrow=2, labels = c("A", "B"), font.label = list(size=20))

################## Figure 2 Mechanisms of Impact ##########################

Mechanisms_byTaxa<-Full3%>%select(RefNum, Taxonomic.Group, X24, Predation, Competition, Disease,
Genetic.Effects,`Habitat.Alteration./.Degradation`, Collateral.Damage.from.ISM, Behavioural.Changes,
Biofouling, Unidentified)
Mechanisms_byTaxa<-gather(Mechanisms_byTaxa, key = "Mechanism", value = "Presence",-
c(RefNum,Taxonomic.Group, X24))
Mechanisms_byTaxa2<-Mechanisms_byTaxa %>% drop_na(Presence)
Mechanisms_byTaxa3<-Mechanisms_byTaxa2 %>% distinct(RefNum, Taxonomic.Group, Mechanism, .keep_all =
TRUE)
Mechanisms_byTaxa3$Mechanism<- gsub("[.]", "\n", Mechanisms_byTaxa3$Mechanism)

ggplot(data = Mechanisms_byTaxa3, aes (x=fct_rev(Mechanism), fill=Taxonomic.Group))+
  geom_bar(stat='count')+
  theme_classic()+
  scale_y_continuous(expand = c(0,0), limits=c(0,80)) +
  theme(axis.text.x = element_text(vjust = 1, hjust = 0.95), text=element_text(size=18)) +
  xlab("Mechanisms of Impact\n") + ylab("\nNumber of SAR") + labs(fill = "Habitat")+
  scale_x_discrete(labels=c("Unidentified", "Predation",
"Habitat\nAlteration/\nDegradation","Genetic\nEffects", "Disease", "Competition",
"Collateral\nDamage\nFrom ISM", "Biofouling","Behavioural\nChanges"))+coord_flip()

################## Figure 1 Mechanisms of Intro and Spread ##########################

#Figure 1 - Top Panel - Mechanism of Introduction
Intro<- read.xlsx("./ISCBC_TrackingTable_20210217_analysis.xlsx", sheet="Invasive Species")
Intro<-Intro[,-c(2:5, 15:28)]
Intro2<-gather(Intro, key = IntroMech, value = "Presence", -c(Invasive.Species))
Intro2<-Intro2 %>% drop_na(Presence)
Intro2$IntroMech<- gsub("[.]", "\n", Intro2$IntroMech)
Intro2.5<- merge(Intro2,InvasivesTaxa, by="Invasive.Species") # Merge to long data format by common
name to assign taxa
intro<-ggplot(data=Intro2.5, aes (x=IntroMech, fill=Invasive.Taxonomic.Group))+
  geom_bar(stat="count")+
  theme_classic()+
  theme(axis.text.x = element_text(vjust = 1, angle = 45, hjust = 1), text=element_text(size=22)) +
  scale_y_continuous(expand = c(0,0), limits=c(0,55)) +
  xlab("\nVector of Introduction") + ylab("Number of IS\n") + labs(fill = "IS Taxonomic Group")+
  scale_x_discrete(labels=c("Accidental\nIntroduction", "Erosion Control", "Forage", "Medicine",
"Consumption\nand/or Recreation", "Ornamental", "Pest Control", "Seed Collection", "Self-
Dispersal"))

#Figure 1 - Bottom Panel - Mechanism of Spread
Spread<- read.xlsx("./ISCBC_TrackingTable_20210217_analysis.xlsx", sheet="Invasive Species")
Spread<-Spread[,-c(2:15, 25:28)]
Spread2<-gather(Spread, key = SpreadMech, value = "Presence", -c(Invasive.Species))
Spread2<-Spread2 %>% drop_na(Presence)
Spread2$SpreadMech<- gsub("[.]", "\n", Spread2$SpreadMech)
spread<-ggplot(data=Spread2, aes (x=SpreadMech, fill = Presence)) +
  geom_bar(stat='count')+
  theme_classic()+
  theme(axis.text.x = element_text(vjust = 1, angle = 45, hjust = 1), text=element_text(size=22)) +
  scale_y_continuous(expand = c(0,0), limits=c(0,45)) +
  scale_fill_manual(values = c("darkorchid2","limegreen"), labels = c("Non-Recreational",
"Recreational")) +
  labs(fill = "Source") +
  xlab("\nVector of Spread") + ylab("Number of IS")+
  scale_x_discrete(labels=c("Animal-Assisted", "Contaminated\nSoil/Plants", "Clothing", "Development
Activities","Pest Control", "Roads/Railways", "Self-Dispersal", "Unauthorized Releases", "Vehicle-
Assisted"))

#Figure 1 - panels for intro and spread combined
ggarrange(intro, spread, ncol=1, nrow=2)

################## Figure 5 Notable Threats ##########################
```

```
Notable<-Full3[,c(2:5,249:260)]
Notable<-Notable[,-12]
Notable2<-gather(Notable, key = OtherThreats, value = "Presence", -c(1:4))
Notable2<-Notable2 %>% drop_na(Presence)
Notable2<-Notable2 %>% distinct(RefNum, OtherThreats, .keep_all = TRUE)
Notable2$OtherThreats<- gsub("[.]", " ", Notable2$OtherThreats)
Notable2$OtherThreats<- gsub(" ", "\n", Notable2$OtherThreats)
ggplot(data = Notable2, aes (x=fct_rev(OtherThreats), fill= Taxonomic.Group))+
  geom_bar(stat='count', width = 0.9)+
  theme_classic()+
  theme(axis.text.x = element_text(vjust = 1, hjust = 0.5), text=element_text(size=22)) +
  scale_y_continuous(expand = c(0,0), limits=c(0,60)) +
  xlab("Other Notable Threats") + ylab("Number of SAR") + labs(fill = "Taxonomic Group")+
  scale_x_discrete(labels=c("Transportation","Pollution","Natural
System\nModification","Natural\nEvents",
                            "Human Intrusions/\nDisturbance", "Geological\nEvents","Energy
&\nMining","Development",
                            "Climate Change &\n Severe Weather","Biological\nResource Use",
"Agriculture"))+
  coord_flip()

################## Figure 4 MAPPING COMPONENTS ##########################
### Read in Map Data

map_ecoprov_orig <- readOGR(dsn="./Shapefiles", "ERC_ECOPRO_polygon",verbose = TRUE)
names(map_ecoprov_orig) #Long names are in column 3 with short title "CPRVNCNM"
list(map_ecoprov_orig$CPRVNCNM) # These are the names we must match and use to merge spatial and
SAR-IS data files
map_ecoprov_orig.df <- fortify(map_ecoprov_orig, region = "CPRVNCNM")

# Plot base shapefile in GGplot
map <- ggplot(data = map_ecoprov_orig.df, aes(x = long, y = lat, group = group))
map +
  geom_polygon(aes(fill = id)) +
  coord_fixed(1.3) +
  guides(fill = FALSE)

# Compute the centroid as the mean longitude and latitude to place labels
# Used as label coordinate for region name labels
# Note I had to restart R after running all code above to get this piece to work
region.lab.data <-
map_ecoprov_orig.df %>%
  group_by(id) %>%
  summarise(long = mean(long), lat = mean(lat))

# A simple text wrapper function (you can expand on this for you needs) - \n substitutes a line
break for spaces
region.lab.data$id <- gsub(" ", "\n", region.lab.data$id)
# Offset certain labels that seem skewed for some reason
region.lab.data$long[3]<- 858152 # Coast and Mountains - original longitude tweaked is 1048152
region.lab.data$long[11]<- 1232476 # Taiga Plains - original longitude tweaked is 1132476
region.lab.data$long[9]<- 1558322 # Southern Interior Mountains - original longitude tweaked is
1132476
region.lab.data$long[5]<- 536443.3 # Northeast Pacific - original longitude tweaked is 636443.3
region.lab.data$long[1]<- 1350523.8 # Boreal Plains - original longitude tweaked is 1280523.8
region.lab.data$lat[1]<- 1288914.0 # Boreal Plains - original lat tweaked is 1238914.0
#Plot with wrapped text labels
ggplot(map_ecoprov_orig.df, aes(x = long, y = lat, label = id)) +
  geom_polygon(aes(group = group, fill = id))+
  geom_text(aes(label = id), data = region.lab.data,  size = 5, hjust = 0.5)+
  # geom_fit_text(reflow = TRUE)+
  # scale_fill_viridis_d()+
  theme_void()+
  theme(legend.position = "none")
ecoprov_map

#Plot BC outline shapefile in GGplot
map_BCOutline_orig <-readOGR(dsn="./ProvOutline", "POL_BND_1M_polygon",verbose = TRUE)
map_BCOutline_orig.df <- fortify(map_BCOutline_orig, region = "OBJECTID")

# Plot Number INV-SAR Impact Pairs by Ecoprovince as heatmap using "EcoSumm"
#Starting point is code from old analyses (may not be more direct route)
Habitat<-gather(InvasivesMatrix3, key = "Hab", value = "YN",-c(RefNum, Taxonomic.Group,
```

```
`Species.at.Risk.(SAR).Common.Name`, Georgia.Depression, Coasts.and.Mountains, Southern.Interior,
Southern.Interior.Mountains, Central.Interior, `Sub-Boreal.Interior`, Boreal.Plains, Taiga.Plains,
Northern.Boreal.Mountains,Northeast.Coast, X24, Invasive, Presence))
Habitat<-Habitat %>% drop_na(YN)
HabitatSumm<-Habitat %>% count(Hab)

#How are impacts (as # SAR - IS impact pairs?) distributed across ecoprovinces?
Ecoprovinces<-gather(Habitat, key = "Ecoprovince", value = "YN2",-c(RefNum,Taxonomic.Group,
`Species.at.Risk.(SAR).Common.Name`,X24, Invasive, Presence, Hab, YN))
Ecoprovinces<-Ecoprovinces %>% drop_na(YN2)
Ecoprovinces$EcoNames<- gsub("[.]", " ", Ecoprovinces$Ecoprovince)
EcoSumm<-Ecoprovinces %>% count(EcoNames)
# Align data names
EcoSumm$EcoNames
unique(map_ecoprov_orig.df$id)
EcoSumm$id <-toupper(EcoSumm$EcoNames)
EcoSumm$id[3] <- "COAST AND MOUNTAINS" #Remove S in coasts to match map labels
# Merge data
map_ecoprov_ecosumm.df <- merge(map_ecoprov_orig.df, EcoSumm, by ="id")
map_ecoprov_ecosumm.df <- map_ecoprov_ecosumm.df[,c(1:7,9)]
map_ecoprov_ecosumm.df <- map_ecoprov_ecosumm.df[order(map_ecoprov_ecosumm.df$order),]

#FIGURE 4 - main panel - choropleth of IS-SAR pairs by Ecoregion - same as bar plot Figure 8
eco_map<-ggplot(map_ecoprov_ecosumm.df, aes(x = long, y = lat, label = id)) +
  geom_polygon(aes( group = group, fill = n))+
  scale_fill_gradient2(low = "white", mid = "yellow",high = "red3", na.value = "gray")+
  geom_path(data = map_BCOutline_orig, aes(group=id), size=0.1, alpha=0.4)+
  geom_path(data = map_ecoprov_orig.df,
            aes(x = long, y = lat, group = group),
            color = "black", size = 0.1, alpha=0.5)+
  geom_text(aes(label = id), data = region.lab.data,  size = 5, hjust = 0.5)+
  theme_void()+
  labs(fill = "Number of\nIS-SAR Pairs")+
  theme(legend.text=element_text(size=16), legend.title = element_text(size=16),legend.position =
c(0.85,0.80))

#Same as above but facet by habitat, adapt code below to choropleth
Habitat<-gather(InvasivesMatrix3, key = "Hab", value = "YN",-c(RefNum, Taxonomic.Group,
`Species.at.Risk.(SAR).Common.Name`, Georgia.Depression, Coasts.and.Mountains, Southern.Interior,
Southern.Interior.Mountains, Central.Interior, `Sub-Boreal.Interior`, Boreal.Plains, Taiga.Plains,
Northern.Boreal.Mountains, Northeast.Coast, X24, Invasive, Presence))
Habitat<-Habitat %>% drop_na(YN)
Ecoprovinces<-gather(Habitat, key = "Ecoprovince", value = "YN2",-c(RefNum,Taxonomic.Group,
`Species.at.Risk.(SAR).Common.Name`,X24, Invasive, Presence, Hab, YN))
Ecoprovinces<-Ecoprovinces %>% drop_na(YN2)
Ecoprovinces$EcoNames<- gsub("[.]", " ", Ecoprovinces$Ecoprovince)
Summ3<-Ecoprovinces %>% count(EcoNames, Hab)
Summ3$EcoNames
unique(map_ecoprov_orig.df$id)
Summ3$id <-toupper(Summ3$EcoNames)

Summ3$id[5:7] <- "COAST AND MOUNTAINS" #Remove S in coasts to match map labels
# Merge data
map_ecoprov_summ3.df <- merge(map_ecoprov_orig.df, Summ3, by ="id")
map_ecoprov_summ3.df <- map_ecoprov_summ3.df[,c(1:7,9,10)]
map_ecoprov_summ3.df <- map_ecoprov_summ3.df[order(map_ecoprov_summ3.df$order),]

#Figure 4 - inset panels - choropleth of IS-SAR pairs by Ecoregion and habitat
habmap<-ggplot(map_ecoprov_summ3.df, aes(x = long, y = lat, label = id)) +
  geom_polygon(aes( group = group, fill = n))+
  scale_fill_gradient2(low = "white", mid = "yellow",high = "red3", na.value = "gray")+
  geom_path(data = map_ecoprov_orig.df,
            aes(x = long, y = lat, group = group),
            color = "black", size = 0.1)+
  theme_void() + facet_wrap (~Hab, ncol=2) + theme(plot.margin=unit(c(0.25, 0.25, 0.25, 0.25),
"cm"))+
  labs(fill = "Number of\nIS-SAR Pairs")+
  theme(legend.text=element_text(size=16), legend.title = element_text(size=16),
        legend.position = c(0.75,0.25),  legend.justification = c(1, 0), strip.text =
element_text(size=14))

#Figure 4 - main panel combined with insets
ggarrange(eco_map, habmap, ncol=1, nrow=2, labels=c("A", "B"), font.label = list(size=20))
```

```
################## Figure 3 threat calculations ############################

Calc<- read.xlsx("./ISCBC_ThreatCalcs_20210217.xlsx")
#reduce to one row per species
Calc2<-Calc %>% separate(Ref.ID, c("RefNum", "RefLet"), "-", remove=FALSE)
Calc3<-Calc2 %>% distinct(RefNum, .keep_all = TRUE)
colSums(!is.na(Calc3))
#Figure 3 Impact panel
Imp<-Calc2 %>% drop_na(Impact)
ImpFig<-ggplot(data = Imp, aes (x=Taxonomic.Group, fill= factor(Impact, levels = c("Very High",
"High", "Medium", "Low", "Negligible", "Not Calculated", "Unknown"))))+
  geom_bar(stat='count')+
  theme_classic()+
  scale_y_continuous(expand = c(0,0), limits=c(0,40)) +
  theme(axis.text.x = element_text(vjust = 0, angle=90, hjust=0.95), text=element_text(size=18)) +
  xlab("Taxonomic Group") + ylab("Number of SAR") +
  scale_fill_manual(values = c("red4", "orangered1","orange1", "yellow1", "olivedrab1", "purple",
"royalblue")) + labs(fill = "Impact Rating")

#Figure 3 Scope panel
Sco<-Calc2 %>% drop_na(Scope)

ScoFig<-ggplot(data = Sco, aes (x=Taxonomic.Group, fill= factor(Scope, levels = c("Pervasive",
"Large", "Restricted", "Small", "Negligible"))))+
  geom_bar(stat='count')+
  theme_classic()+
  scale_y_continuous(expand = c(0,0), limits=c(0,40)) +
  theme(axis.text.x = element_text(vjust = 0, angle=90, hjust=0.95), text=element_text(size=18)) +
  xlab("Taxonomic Group") + ylab("Number of SAR") +
  scale_fill_manual(values = c("red4", "orangered1","orange1", "yellow1", "olivedrab1")) + labs(fill
= "Scope Rating")

#Figure 3 Severity panel
Sev<-Calc2 %>% drop_na(Severity)
SevFig<-ggplot(data = Sev, aes (x=Taxonomic.Group, fill= factor(Severity, levels = c("Extreme",
"Serious", "Moderate", "Slight", "Negligible", "Unknown"))))+
  geom_bar(stat='count')+
  theme_classic()+
  scale_y_continuous(expand = c(0,0), limits=c(0,40)) +
  theme(axis.text.x = element_text(vjust = 0, angle=90, hjust=0.95), text=element_text(size=18)) +
  xlab("Taxonomic Group") + ylab("Number of SAR") +
  scale_fill_manual(values = c("red4", "orangered1","orange1", "yellow1", "olivedrab1",
"royalblue")) + labs(fill = "Scope Rating")

#Figure 3 Timing panel
Tim<-Calc2 %>% drop_na(Timing)
TimFig<-ggplot(data = Tim, aes (x=Taxonomic.Group, fill= factor(Timing, levels = c("High",
"Moderate", "Low", "Insignificant"))))+
  geom_bar(stat='count')+
  theme_classic()+
  scale_y_continuous(expand = c(0,0), limits=c(0,40)) +
  theme(axis.text.x = element_text(vjust = 0, angle=90, hjust=0.95), text=element_text(size=18)) +
  xlab("Taxonomic Group") + ylab("Number of SAR") +
  scale_fill_manual(values = c("red4","orange1", "yellow1", "olivedrab1")) + labs(fill = "Timing
Rating")

#Figure 3 - all panels combined
ggarrange(ImpFig, ScoFig, SevFig, TimFig, ncol=2, nrow=2, labels = c("Impact", "Scope", "Severity",
"Timing"), label.x = 0.1)
```

Appendix C: Threat Calculator Conversion Rubric

Two different tools are used to assess threats in Status Report and Recovery Strategy documents. Since 2012, COSEWIC has used the International Union for the Conservation of Nature (IUCN) Threat Calculator (detailed in Master et al. 2012) to assess threats in COSEWIC Status Reports (COSEWIC 2012, 2019). This same IUCN calculator is generally used in Recovery Strategies that are prepared by Environment and Climate Change Canada, though a few exceptions exist. Fisheries and Oceans Canada (DFO) uses a different threats calculator (herein referred to as the non-IUCN calculator) when preparing Recovery Strategies and Management Plans (DFO 2014). Though specific documentation was not found for it, the calculator used in Recovery Strategies prepared by Parks Canada Agency appears to be the same non-IUCN calculator that is used by DFO. Examples of recovery strategies using the IUCN Threat Calculator include those for Victoria's Owl clover and the Western Rattlesnake, while examples of those using the non-IUCN Threat Calculator include those for Foothill Sedge and the Misty Lake Sticklebacks.

Although terminology differs between the IUCN and non-IUCN threat calculators, definitions for the ratings in each calculator are detailed enough to allow the categories to be aligned in a manner that is sufficient for the purpose of summary analysis in this study (see Table C-1). The non-IUCN Threat Calculator featured fewer possible ratings than the IUCN Threat Calculator, so in some cases we documented the conversion as a range. For example, if a species' non-IUCN '**Extent**' rating was 'High', we recorded this as 'Pervasive-Large' under the IUCN Threat Calculator's '**Scope**' ratings.

Table C-1: Definitions and corresponding threat rating categories of the non-IUCN and IUCN Threat Calculators used to document the magnitude of invasive species threats in species at risk assessments. For the purposes of this study, magnitude of impact ratings created using the non-IUCN Threat Calculator were converted to the closest corresponding magnitude of Impact rating class under the IUCN Threat Calculator.

Non-IUCN	IUCN
Extent	**Scope**
Proportion of the species affected by the threat.	*Proportion of the species that can reasonably be expected to be affected by the threat within 10 years. Usually measured as a proportion of the species' population in the area of interest.*
High	**Pervasive** (71-100%)
	Large (31-70%)
Medium	**Restricted** (11-30%)
Low	**Small** (1-10%)
Severity	**Severity**
Magnitude of impact caused by the threat and level to which it affects species conservation. Reflects the population-level effect.	*Within the scope, the level of damage to the species from the threat that can reasonably be expected to be affected by the threat within a 10-year or three-generation timeframe. Usually measured as the degree of reduction of the species' population.*

Non-IUCN	IUCN
High (Very large population-level effect)	**Extreme** (71-100%)
	Serious (31-70%)
Moderate	**Moderate** (11-30%)
Low	**Slight** (1-10%)
	Negligible (<=1%)
	Neutral or Potential Benefit (>=0%)
Occurrence	**Timing**
Timing of occurrence of the threat and describes whether a threat is historical, current, and/or anticipated.	
Current	**High** - Continuing
Anticipated	**Moderate** - Only in the future (could happen in the short term [<10 yrs or 3 generations) or now suspended (could come back in the short term)
	Low - Only in the future (could happen in the long term) or now suspended (could come back in the long term)
	Insignificant - Only in the past and unlikely to return, or no direct effect but limiting.

The IUCN threat calculator's **'impact'** rating is based on the interaction between scope and severity ratings for present and future threats only. The IUCN Threat Calculator Template, available as part of the BC Government's online recovery planning guidance, was used to calculate **'impact'** after converting non-IUCN calculations of scope and severity. The template impact calculations generally follow the matrix shown in Table X, however it allows input and output of ranges (e.g., High – Low).

Table C-2: A matrix showing the resulting IUCN impact rating based on the interaction of scope and severity ratings for present and future threats. Adapted from the BC Government's IUCN Threat Calculator Template (available here).

		Scope			
		Pervasive	Large	Restricted	Small
Severity	Extreme	Very High	High	Medium	Low
	Serious	High	High	Medium	Low
	Moderate	Medium	Medium	Low	Low
	Slight	Low	Low	Low	Low
