ECOSYSTEM SERVICES AS AN OUTREACH STRATEGY FOR INVASIVE KNOTWEED CONTROL

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ABSTRACT

Ecosystem Services as an Outreach Strategy for Invasive Knotweed Control

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Knotweed (*Polygonum spp.*) has invaded and degraded riparian habitats across much of Europe and North America. In response, conservation groups engage in an annual struggle to mitigate and reverse the invasion, attempting to extirpate the plant from affected watersheds. Knotweed scholarship has characterized many invasion impacts, while also helping to improve treatment methods. However, knotweed scholarship has neglected to inform effective outreach strategies, which are essential for successful knotweed control. This thesis considers ecosystem services as a framework for improving those outreach strategies. It asks whether landowners express greater concern for environmental features related to either ecosystem services or ecosystem integrity. To answer this question, I coordinated with King County Noxious Weeds to survey 1,016 landowners important to their knotweed control program. We received 219 complete responses for a 21.6% survey response rate. Landowners expressed greatest concern for the two environmental features related to ecosystem services, "streambank stability (erosion)" and "salmon/fish stocks," with 70.9% and 62.3% answering "significant concern," respectively. Landowners expressed less concern for the two features related to ecosystem integrity, "native plant community health" and "overall biodiversity," with 44.1% and 47.7% answering "significant concern," respectively. This thesis also examines how knotweed invasion affects ecosystem services to provide a comprehensive assessment of using ecosystem services as a framework for landowner outreach. I conclude that knotweed outreach should always focus on how the plant causes erosion because concern for landowners express widespread concern for this environmental feature. More broadly, this thesis' findings support using ecosystem services as a framework for public outreach concerning environmental issues.

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Introduction

Invasive species are an unfortunate reality for almost every ecosystem on the planet. In the age of globalization, humanity has spread countless flora and fauna to every corner of the globe. Most of these species prove relatively innocuous, either quickly dying off or remaining limited to their introduced population levels. However, many non-native species proliferate in their new ecosystems, which lack the natural population checks found in their native ranges. Among these proliferating non-native species, some will actively harm the ecosystems that they spread into and therefore earn the distinction of an invasive species.

Knotweed (*Polygonum spp.*) is considered one of the world's 100 most invasive species (Lowe et al., 2000). Native to East Asia, knotweed has spread across much of North America and Europe. It aggressively invades along waterways to establish in the adjacent riparian zones. Once established, knotweed roots quickly spread out into nearby soils. Shoots emerge from the soil every spring and can grow up to four meters tall. These shoots resemble a floppy bamboo and produce large overlapping leaves. Knotweed invasion commonly results in dense, monotypic stands that suppress native plants in the area. One might describe the space below a full-grown knotweed forest as a "dead zone."

The academic community has responded to this problem by closely examining how knotweed invades and dominates native ecosystems. For example, researchers have identified clonal reproduction from broken off root fragments as knotweed's primary means of spreading. Conservation groups have also committed more than a decade of control work toward eliminating knotweed infestations. Knotweed researchers have successfully collaborated with knotweed control groups to improve knotweed eradication efforts in several important ways. One such example of successful collaboration helped control groups identify late summer as the most effective time to treat knotweed with herbicide (Bashtanova et al., 2009). Without this collaboration between academics and the conservation network, the knotweed invasion would be much worse than we see today.

However, a critical disconnect has developed between the knotweed scholarship and its application toward knotweed control. This disconnect is best understood through the lens of a third, critically important and underrepresented stakeholder: the landowner whose property the knotweed invades. Without 100% landowner participation in knotweed control programs, untreated knotweed will continually spread into surrounding areas. Therefore, encouraging landowner participation represents an essential step toward achieving local knotweed eradication. Academics exhaustively focus research on the biological impacts of knotweed invasion with little consideration for how persuasive these biological impacts are to landowners. This focus on biological impacts ignores the pressing need to develop more effective outreach strategies and materials for reluctant landowners.

This thesis aims to bridge the disconnect between a biocentric knotweed literature and the anthropocentric values of many landowners. Bridging this disconnect should greatly improve knotweed control at a landscape scale by helping conservation groups advance closer to 100% landowner participation.

The ecosystem services literature could hold the key to framing biocentric knotweed research in an anthropocentric light. By definition, an ecosystem services framework attempts to show how environmental systems can benefit humanity. The existing knotweed literature closely examines how knotweed might affect several environmental systems, so applying an ecosystem service's framework to the knotweed literature should help illuminate how knotweed invasion could affect anthropocentric landowner values. My first research question is: *how does knotweed invasion affect ecosystem services, based on existing scholarship?*

The knotweed literature points to several significant impacts to ecosystem services. The strongest impacts come from fish habitat degradation. Knotweed can disrupt food web dynamics (Lecerf et al., 2007; Gerber et al., 2008) and hinder structural habitat features such as tree recruitment (Urgenson et al., 2008). Fish directly provide several provisioning and cultural services. The literature also suggests extreme knotweed water-use that could diminish both water availability and water quality (Vanderklein et al., 2014). Overall, the knotweed scholarship strongly suggests a negative impact on fish and water-related ecosystem services.

In contrast to researchers who overlook the importance of landowner outreach, knotweed control groups compose their outreach materials for an anthropocentric audience. For instance, knotweed info sheets widely reference knotweed's potential to break through pavement, despite this claim lacking peer-reviewed validation. Such a threat to human-built environment would surely pique the interest of many landowners. The conservation network has informally applied an anthropocentric framework to knotweed impacts as an outreach strategy, but an ecosystem services framework could provide more direction and clarity to this strategy.

In using an ecosystem services framework, the knotweed literature can be contrasted against knotweed outreach materials to better inform future actions by both parties. For academia, examining the anecdotal evidence found across many knotweed outreach materials could direct future research questions. For example, a study could quantify knotweed's effects on erosion in comparison to other native plants. For the conservation network, knotweed literature might reveal impacts to ecosystem services that most outreach materials do not consider. For example, recent research points to intensive knotweed water-use and this anthropocentric impact remains absent from most outreach materials (Vanderklein et al., 2014).

Fostering closer collaboration between knotweed researchers and the conservation network will help advance the global knotweed control effort. Most directly, closer collaboration will bring academia into the fold of providing persuasive research for landowner outreach. Armed with such research, knotweed control groups can move closer to 100% landowner participation, thus opening the door to potential knotweed eradication from local watersheds. My second research question is: *do landowners express greater concern for environmental features more closely related to either ecosystem services or ecosystem integrity?*

To answer this question, I coordinated with King County Noxious Weeds to conduct a landowner survey. By determining the environmental concerns of landowners, knotweed control groups can compose more targeted outreach strategies that better encourage participation in control programs. Further, the survey results can inform researchers about which knotweed impacts are especially important to the public. As an extension of the discussion around knotweed's impacts on ecosystem services, I hypothesize that landowners will express greater concern for environmental features related to ecosystem services over ecosystem integrity. If the survey data supports this hypothesis, this thesis will provide a theoretical framework for using ecosystem services to compose more persuasive public outreach strategies concerning environmental issues.

The body of this thesis begins with a literature review examining knotweed invasion from its initial introduction in Europe to its current spread across much of North America as well. The literature review will then conclude by considering the scholarship that informs knotweed management. Transitioning into applied theory, this thesis provides a snapshot of the current outreach strategies for various knotweed brochures and websites. The landowner survey then tests these outreach strategies against underlying concerns for environmental features. The proceeding discussion section introduces several important conclusions around landowner concerns. The body of this thesis concludes with an extended examination of how knotweed invasion affects various ecosystem services, based on existing scholarship. In the final section, this thesis provides suggestions for improving outreach strategies and possible future research questions.

Literature Review

Chapter 1: The invader

Knotweed is considered one of the world's largest herbaceous plants and possesses an extensive perennial root system (Hollingsworth & Bailey, 2000). Knotweed roots quickly spread into adjacent soils and annually produce above ground shoots that emerge in the spring, flower in the summer, and die back with the first frost in the fall. Knotweed shoots bow over on the upper half of the plant to allow for maximum light exposure to its broad heart-shaped leaves. During the summer, a fully established knotweed patch presents as a densely growing thicket of shoots and leaves that can reach as tall as 5 meters in height (Wilson, 2007).

In its native habitats across the coastal regions of East Asia, knotweed occurs as an early successional species on volcanic slopes and other recently disturbed areas (Seiger, 1984). For these East Asia ecosystems, natural checks such as herbivory and disease keep knotweed populations under control. In most cases, hardier plants such as bamboo eventually outcompete even fully established knotweed patches, allowing for successional pathways to continue. For bamboo, a similar method of root spreading likely assists in its successful competition against knotweed.

Knotweed originally arrived in Europe and later North America with a good amount of public fanfare and excitement. The Society of Agriculture and Horticulture at Utrecht awarded Japanese knotweed (*Polygonum cuspidatum*) with the gold medal in 1847 for the most interesting new ornamental plant, with special mention of the plant's "great vigor" (Bailey & Conolly, 2000). Several years later, horticulturalists brought Japanese knotweed across the English Channel to the United Kingdom (Bailey & Conolly, 2000) and in 1876 it arrived on the East Coast of the United States (Barney, 2006). Unfortunately, Europe and the US lack the natural checks that control knotweed populations in its native range. For example, knotweed demonstrated high resistance to herbivory in comparison to two native European plants (Krebs et al., 2011). Thus, an invasive plant emerged.

Amazingly, the first wave of knotweed invasion swept across the UK as a single female genome of Japanese knotweed. The introduced female clone was male-sterile, disallowing any intra-species sexual reproduction (Brock et al., 1995). Despite a total absence of seed dispersal, this female genome aggressively invaded the UK through its capacity for clonal spreading. Explicitly, Japanese knotweed can grow a new plant from broken off root or stem fragments as small as an inch in length (WSDA, 2013). The famous “UK Clone” remains a persistent invader to this day, composing a vast majority of the UK knotweed population and approximately half of the East Coast knotweed population in the US (Grimsby & Kesseli, 2010). Even considering Japanese knotweed’s intercontinental invasion, a yet more invasive species of knotweed was still to come.

The potential for a more invasive species of knotweed arrived in the form of a less invasive species of knotweed, Giant knotweed (*Polygonum sachalinensis*). In comparison to Japanese knotweed, Giant knotweed roots spread more slowly and it cannot clone itself as effectively – thus limiting its invasiveness. The significance of Giant knotweed stems from its sexual vitality. A single flower from a Giant knotweed plant can produce up to 8,000 grains of pollen (Tiebre et al., 2007). In a sample of ten Giant knotweed plants from a single population, Gaskin et al. (2014) found only a single duplicate genome. Such genetic diversity points to seed spreading as Giant knotweed’s dominant form of reproduction. Giant knotweed’s tendency for seed spreading stands in stark contrast to Japanese knotweed’s total reliance on clonal spreading.

Unfortunately for many European and North American ecosystems, male patches of Giant knotweed successfully pollinated the prevalent female Japanese knotweed clone. Giant knotweed and Japanese knotweed combined to produce the hybrid Bohemian knotweed (*Polygonum x bohemicum*). Interestingly, the birth of Bohemian knotweed initially carried little concern as reports from the widely invaded UK indicated an extreme rarity of this hybridization (Bailey et al., 2007). However, it soon became clear that the UK's limited hybrid occurrence did not apply to many other regions in both Europe and North America. Bzdega et al. (2012) found evidence of extensive hybridization in Central Europe, while Grimsby and Kesseli (2010) found similar evidence of widespread hybridization in knotweed populations across Eastern North America. Bohemian knotweed's invasiveness appears most pronounced in Western North America where Gaskin et al. (2014) estimated the hybrid to account for an astounding 71% of the knotweed population.

Where Bohemian knotweed successfully spreads, the hybrid represents the most invasive knotweed species. In these regions, Bohemian knotweed maintains the capacity for clonal reproduction that helped Japanese knotweed spread across the UK. For example, researchers found only a single Bohemian knotweed genotype in an extensive infestation on the riverbanks of the Chaudiere River in Quebec (Duquette et al., 2015). At the same time, Bohemian knotweed grows to taller heights like Giant knotweed and can incredibly produce almost 3x more biomass than Japanese knotweed (Parepa et al., 2014). The net effect is a plant that can quickly spread through clonal or seed dispersal and then dominates an area once established.

The existing literature gives us a solid foundation around how knotweed invasion degrades ecosystem integrity. The majority of the knotweed scholarship considers knotweed's invasion methods and its mechanisms for impacting native plant communities. However, only two studies have directly quantified knotweed's impacts on native plant communities. Urgenson et al. (2009) found that riparian knotweed invasion lowered native plant abundance and richness. Stoll et al. (2012) observed a 50% reduction in plant species richness on average for plots invaded by Japanese knotweed. For quantifying indirect impacts, the literature also examines knotweed's negative impacts on light availability (Urgenson et al., 2012) and soil quality (Parepa et al., 2012), which carry important implications for native plant communities.

Several studies have shown how knotweed can dramatically impact lower trophic levels within an ecosystem. Gerber et al. (2008) found that knotweed invasion lowered invertebrate abundance by almost 50%. Topp et al. (2008) found lower beetle diversity, richness, and total abundance in plots invaded by Japanese knotweed. Maerz et al. (2005) found that green frogs within Japanese knotweed patches foraged for food less successfully, and in turn, demonstrated lower average mass. Stoll et al. (2012) found that Japanese knotweed invasion reduced average snail species richness. In considering all of these findings around how knotweed impacts both plant communities and lower trophic levels, we can see significant negative effects on ecosystem integrity.

Chapter 2: Knotweed management

Land managers primarily focus knotweed control efforts along riparian corridors. While capable of invading a wide range of habitat types, knotweed most aggressively spreads along river systems. Due to its capacity to establish from small root or stem fragments, annual flooding serves to carry infestations downstream. This spreading mechanism proves especially effective on rivers with active floodplains. Knotweed's tolerance for poor soils also contributes to its aggressive riparian spreading, allowing the plant to establish on gravel bars ahead of native plant succession.

Riparian knotweed invasion presents unique management challenges around landowner participation. Without landowner participation to eliminate the knotweed on a given property, the knotweed will continually spread downstream with annual flooding. However, needing landowner participation to accomplish landscape scale invasive species control is not unique to knotweed management. Epanchin-Niell et al. (2010) describe the challenge of controlling invasive plants across discrete land parcels as a 'management mosaic.'

In the case study, Epanchin-Niell et al. (2010) explore, ranchers must work together to control invasive yellow starthistle (*Centaurea solstitialis*) in the foothills of the Sierra Nevada in California. Epanchin-Niell et al. (2010) found that each landowner only assumes responsibility for the invasive impacts on their own land. Therefore, as lands are subdivided, each individual landowner assumes a smaller responsibility for the overall impact of the plant invasion, which in turn decreases incentives to participate in landscape-scale control efforts (Epanchin-Niell et al., 2010). In relation to knotweed control, riparian land parcels are often highly subdivided because water access typically raises a property's value. Therefore, riparian management mosaics invaded by knotweed often occur with a low individual incentive for participation due to smaller parcel sizes.

Examining a more typical management mosaic further illustrates the elevated importance of individual landowner participation for riparian knotweed control. The social landscape for controlling an invasive species such as yellow starthistle could be described as a 'radial management mosaic'. The starthistle can spread in several different directions through wind dispersal so the invasion range is likely widespread but more diluted. Therefore, individual landowner participation importance is most directly tied to parcel size and the degree of infestation. In contrast, the social landscape for controlling riparian knotweed could be described as a ‘linear management mosaic’. The most upstream infestation always represents the most critical point for control because the knotweed will continually spread downstream from this source infestation. In response, land managers always begin knotweed control efforts at the most upstream infestation and then work downstream from there. As knotweed management moves downstream, any holdout landowner can effectively halt momentum toward landscape-scale knotweed control.

To overcome the challenges of a management mosaic, Holman et al. (2010) outline several effective outreach strategies for encouraging participation from small private landowners. These outreach strategies were developed over a decade of effort toward controlling knotweed invasion in the Skagit River watershed in Washington state. Holman et al. (2010) state that “landowners are most likely to participate if they:

- understand the purpose and benefits of treatment;
- recognize that little or no money and/or effort is required from them;
- trust the people doing the work;
- and/or that friends and neighbors are also participating in the project.”

In examining these factors encouraging landowner participation, “understanding the purpose and benefits of treatment” represents the only factor dependent upon the knowledge imparted by the existing knotweed literature. Therefore, we must examine how the knotweed literature describes the impacts of knotweed invasion in order to determine its utility for communicating “the purpose and benefits of treatment” (Holman et al., 2010).

As a framework for considering landowner outreach methods, we can employ the concept of ‘ecosystem services’. Providing context through ecosystem services has become a popular tool for explaining local environmental issues. Broadly speaking, ecosystem services “represent the benefits human populations derive, directly or indirectly, from ecosystem functions” (Costanza et al., 1997). In the case of riparian knotweed invasion, we can examine the literature to ask how knotweed invasion threatens ecosystem services.

In returning to the concept of a management mosaic, the value of an ecosystem services framework for landowner outreach becomes clear. With a management mosaic, the major breakdown in the incentive structure stems from a perceptual disconnect between the impacts of the invasive species on a landowner’s own property and the cascading impacts of denying participation for the broader landscape scale control effort. In other words, “landowners… tend to make control decisions based only on damages occurring on their own land, leading to a lack of control and increased invasion of the landscape” (Epanchin-Niell et al., 2010). An ecosystem services model strengthens an individual’s incentive to aid landscape scale invasive species control by connecting the landscape impacts of the invasion directly to the landowner’s values. This direct connection between knotweed impacts and landowner values also helps them “understand the purpose and benefits of treatment”, a critical strategy for encouraging landowner participation in knotweed control programs (Holman et al., 2010). In summary, an ecosystem services model brings knotweed impacts out of the abstract and into direct relationship with the landowner's property and values.

However, within the existing knotweed literature, an ecosystem integrity framework takes priority over examining ecosystem services. The existing ecosystem integrity model has brought significant benefit to a scientific understanding of the knotweed invasion and how to best counter the invasion. Where this model breaks down is in communicating these findings to landowners, which represents a critical limiting factor for the success of knotweed control programs. To persuade landowners under an ecosystem integrity model, the landowner requires either: an intrinsic value placed upon ecosystem integrity; or a deep enough understanding of the ecosystem as a whole to connect ecosystem integrity impacts to ecosystem services that affect them personally. Some landowners might meet these requirements, but the ecosystem integrity model likely presents too much of a knowledge barrier to resonate with many landowners. In conclusion, knotweed impacts on ecosystem integrity should remain important considerations for management decisions, but communicating how knotweed affects ecosystem services should dramatically improve landowner outreach strategies.

Testing Outreach Strategies

Chapter 3: Current outreach strategies

Understanding and improving landowner outreach strategies begins with an examination of the outreach materials currently available. In looking over these outreach materials, which include brochures or invasive plant profiles, knotweed control groups already seem to focus on ecosystem services a lot more than the knotweed scholarship does. Specifically, most outreach addresses how knotweed invasion affects erosion, an effect of invasion that's notably absent from the knotweed scholarship. Some outreach sources also addressed how knotweed invasion affects fish, which provide several types of ecosystem services for people.

To quantify my subjective assessment of current knotweed outreach strategies, I conducted something like a "convenience web survey" of the first 20 knotweed brochures that I could find through the Google search engine. The majority of these brochures were identified using the search phrase, "knotweed brochure", while the remainder were found using "knotweed pamphlet" and "knotweed info" (Appendix A). I used several sample filters that excluded several of the brochures that I found: 1) must include an "impacts" section – some brochures only discussed control identification or control methods; 2) must come from a currently-operating knotweed control group – some were non-profits and others were government programs; and 3) no duplicate language – some brochures copy and pasted their language from other brochures. Each brochure was sampled for the inclusion of language discussing knotweed impacts on the environmental features from the landowner survey, excluding "the local environment in general".

The results of this anecdotal survey were pretty much as expected. "Native plant community health" was the most commonly referenced impact with 19/20 including some type of language about how knotweed crowds out native plants. "Streambank stability (erosion)" was the next most commonly referenced impact, with 15/20 brochures including relevant language. "Salmon/fish stocks" and "biodiversity" were somewhat less common with 11/20 and 9/20, respectively. "Tree seedling growth/survival" was by far the least commonly included impact, with only 1/20 brochures including this language.

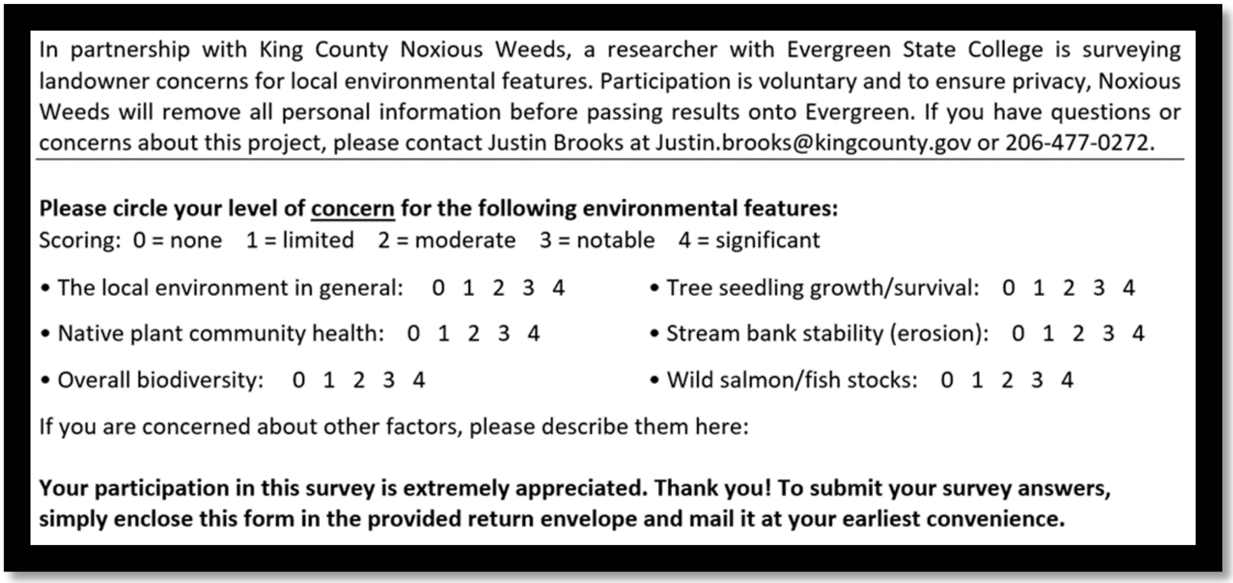
The most notable among these results is the strong consensus around how knotweed causes erosion. Referencing erosion in 15/20 brochures is an especially high figure when considering the absence of published studies on the subject. Later, this thesis will explore the reasoning as to why there’s such strong consensus among the knotweed control community that knotweed causes erosion. For salmon/fish, the lower level of focus at 11/20 could be due to geographic variability because these brochures were sampled from a wide range of areas in the United States. If fish are not prevalent in an area then it would make sense for outreach materials to focus on different strategies.

Chapter 4: Landowner survey methods

The next step in assessing outreach strategies is to test landowner concerns. This section attempts to answer: *do landowners express greater concern for environmental features more closely related to either ecosystem services or ecosystem integrity?* To answer this question, I conducted a comparative analysis of the differing outreach models using a landowner survey asking landowners about their levels of concern for different environmental features in their local environment. Specifically, I collaborated with the King County Noxious Weed Program to survey the landowners currently participating in their knotweed control program. The King County knotweed program is well respected in both the community and the broader conservation network. Without their hard work in developing an extensive participating-landowner portfolio, this survey would not have been possible. In total, 1016 surveys were sent out to King County landowners important to the County’s knotweed control program. Most of these landowners were either currently participating in the program or had previously been involved and needed to renew their agreements. The rest were not-yet involved and a few were real hold-outs from previous outreach efforts. Several landowners had asked to not receive any mail from the county and in turn, did not receive this survey. Properties were located along the Cedar River, Skykomish River, Green River, and Snoqualmie River.

Several considerations went into formulating this landowner survey. The most critical objective was to keep the survey short and simple while parsing out as much information about landowner concerns as possible. Therefore, the survey asked only six simple questions and did not require any writing. Each question asked the landowner to rate their *level of concern* for a certain environmental feature on a 0-4 scale: with 0 indicating "none"; and 4 indicating "significant."

Figure 1: Landowner survey form



In partnership with King County Noxious Weeds, a researcher with Evergreen State College is surveying landowner concerns for local environmental features. Participation is voluntary and to ensure privacy, Noxious Weeds will remove all personal information before passing results onto Evergreen. If you have questions or concerns about this project, please contact Justin Brooks at Justin.brooks@kingcounty.gov or 206-477-0272.

Please circle your level of <u>concern</u> for the following environmental features:
Scoring: 0 = none 1 = limited 2 = moderate 3 = notable 4 = significant

- The local environment in general: 0 1 2 3 4
- Native plant community health: 0 1 2 3 4
- Overall biodiversity: 0 1 2 3 4
- Tree seedling growth/survival: 0 1 2 3 4
- Stream bank stability (erosion): 0 1 2 3 4
- Wild salmon/fish stocks: 0 1 2 3 4

If you are concerned about other factors, please describe them here:

Your participation in this survey is extremely appreciated. Thank you! To submit your survey answers, simply enclose this form in the provided return envelope and mail it at your earliest convenience.

Through the lens of landowner outreach to encourage participation in knotweed control programs, a landowner's *level of concern* serves as a very relevant point of consideration. Knotweed impacts on an ecosystem are diverse and numerous, and outreach materials need to impart a concise and persuasive argument about the needs to control knotweed. Thus, understanding which environmental features are of greatest concern to landowners will surely help knotweed programs compose more persuasive outreach materials.

Each environmental feature included in the survey was selected for a different reason with the intention of contrast against each other. The first feature was intended to serve as a baseline: “the local environment in general.” In examining the other features, this baseline concern indicates whether other features are more or less persuasive than a generalized argument about knotweed degrading the environment. The second and third features reflect the ecosystem integrity model of the existing knotweed research: “native plant community health” and “overall biodiversity.” The following two features reflect important ecosystem services that could be impacted by knotweed invasion: “Streambank stability (erosion)” and “wild salmon/fish stocks.” The final feature relates to a study showing a powerful impact from knotweed invasion: “Tree seedling growth/survival” (Urgenson et al., 2012). This feature’s inclusion intends to parse out the specific dynamics that might make the other features more or less persuasive. Similar to the erosion and fish features, tree seedlings are a concrete entity – not abstract like plant communities or biodiversity. On the other hand, tree seedlings are not so easily relatable as the other concrete features (erosion and fish). In other words, what makes an environmental feature persuasive? Its concrete nature or its relatability?

The survey intentionally did not include any language specific to knotweed impacts. This omission was intended to isolate landowner concern for environmental features, independent from their perceptions of how knotweed might impact those features. To illustrate this dynamic, a landowner might be very concerned about “salmon/fish stocks”, but doesn’t understand how knotweed would impact that environmental feature - and consequently mark their concern as a 0 or a 1, instead of a 4. Introducing knotweed into the survey would muddy the results because we would not know if the environmental feature itself drove the level of concern; or how the landowner believes that knotweed would impact that feature. Better to isolate concern for environmental features and then separately examine how knotweed impacts could persuade landowners in relation to their underlying concerns.

To analyze the survey results, I employed several different statistical tests: 1) a mean analysis; 2) a frequency analysis; 3) an outlier assessment; and 4) an ordinal regression. The mean analysis intends to answer the central question of which environmental features are landowners most concerned about? Before going further, it should be noted that a mean analysis is a flawed central tendency for this survey. This flaw manifests in the difference between ordinal and interval data: mean analysis depends on an equal distance between scores, which cannot necessarily be assumed for a survey using a Likert Scale. In other words, the distance between “limited concern” and “moderate concern” cannot be assumed equivalent to the distance between “moderate concern” and “notable concern.” Susan Jameison (2004) summarizes the issue that using mean to analyze ordinal data “increases the chance of coming to the wrong conclusion about the significance (or otherwise) of his research.”

However, I still rely on a mean analysis for two important reasons: 1) using numbers on the survey sheet lends itself to the landowners perceiving an equal distance between scores, and 2) mean is the central tendency that best represents the data. For the first reason, the flawed assumption still remains but the use of numbers on the survey sheet greatly mitigates the probability of this flaw manifesting in landowner responses. In other words, people are conditioned to perceive an equal distance between sequential numbers, so landowners seeing sequential numbers on a survey sheet probably prompts them to perceive an equal distance between scores. For the second reason, the survey results do not suggest any misleading conclusions from looking at the mean. In contrast, median and mode both suggest misleading conclusions. Median suggests a greater difference between scoring tendencies than is true, while mode suggests zero meaningful difference between scoring tendencies. Both of these conclusions would be wrong. This second reasoning for using a mean analysis is certainly ad hoc, but mean remains the most representative central tendency for the data.

To supplement the mean analysis, I provide a frequency percentage of landowners scoring “4: significant concern.” The mode for each environmental feature is “4: significant concern”, so we can begin to assess the broader trends of the data by examining the frequencies for this response. A frequency percentage also benefits from no flawed assumptions. However, this statistic fails to account for outliers and is slightly less intuitive than the mean. Therefore, I still rely on mean for the bulk of my results discussion for a more comprehensive and easily understood analysis. This frequency percentage is most important for providing an un-flawed statistic that roughly aligns with the results suggested by the mean. Given this alignment between the mean and the frequency of “4: significant concern” responses, we can proceed to discuss the more-nuanced mean analysis with greater confidence that we aren’t coming to any “wrong conclusions,” as Jameison (2004) indicates that we should be wary of.

The outlier assessment intends to provide some idea of which environmental features landowners feel strongly positive or negative toward relative to the other features. This assessment will be sensitive to the degree of greater or less concern. When a survey respondent scores one feature higher or lower than any other feature, it will be assigned a positive or negative score proportional to its distance from the next closest feature. For example, if a landowner answered all “4s” but a “1” for overall biodiversity then that feature would receive a negative outlier score of 3 for that landowner. The overall positive and negative scores will be divided by 219 for each feature to provide an average outlier degree. Positive outlier results can be expected to align with the mean hierarchy analysis. However, the negative outlier results could point to features being divisive for certain landowners, which might not manifest in the mean results. Such divisiveness could be an important consideration when contacting more stubborn landowners. These landowners might develop a negative association if they are presented with a divisive reasoning for knotweed control.

The ordinal regression intends to determine the correlation strength between “general concern for the environment” and the other environmental features. Stronger correlations would suggest that concern for specific environmental features is dependent on an underlying concern for the “local environment in general.” In contrast, a weaker correlation would suggest concern for an environmental feature that transcends the broader association with environmentalism.

Chapter 5: Landowner survey results

King County landowners came through on this survey to provide an encouraging sample size and response rate. King County Noxious Weeds mailed out 1,016 surveys, and we received 243 survey responses. 24 survey respondents failed to complete the full survey, so we ended up with a sample size of 219 for a 21.6% survey response rate. At a standard 95% confidence interval, this response rate for the given population produces a +/- 6% margin of error. In other words, there's a 95% confidence level that the survey results indeed represent the broader population +/- 6% of a given survey result. Public surveys of large populations do not often achieve high response rates, so a +/- 6% margin of error represents a strong output for this survey (Appendix B).

Figure 2: Survey results for "the local environment in general"

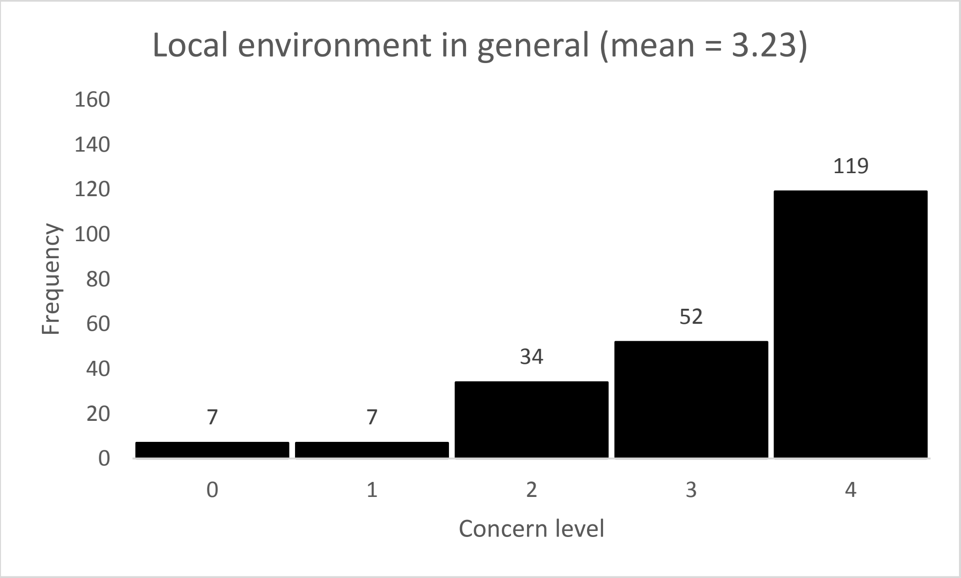


Figure 3: Survey results for "native plant community health"

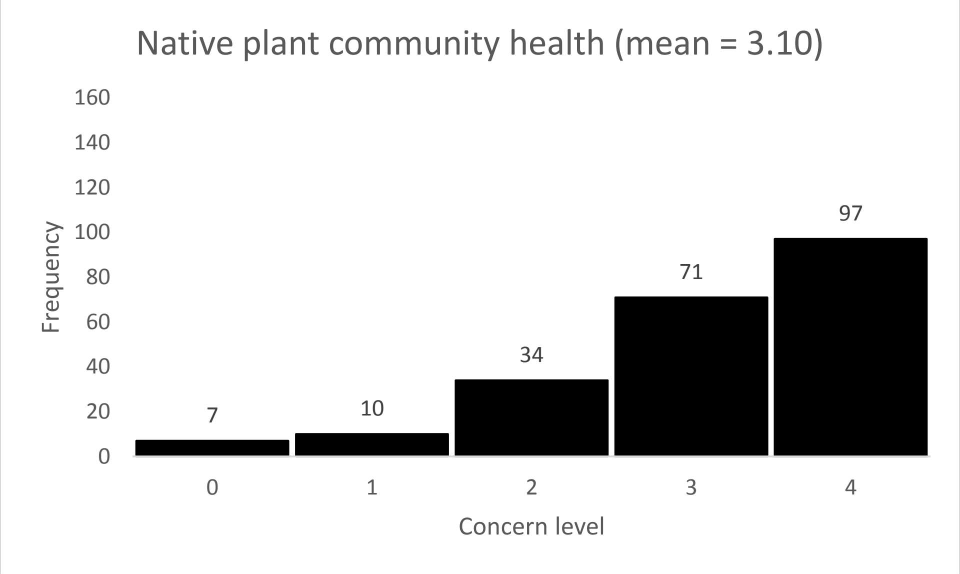


Figure 4: Survey results for "overall biodiversity"

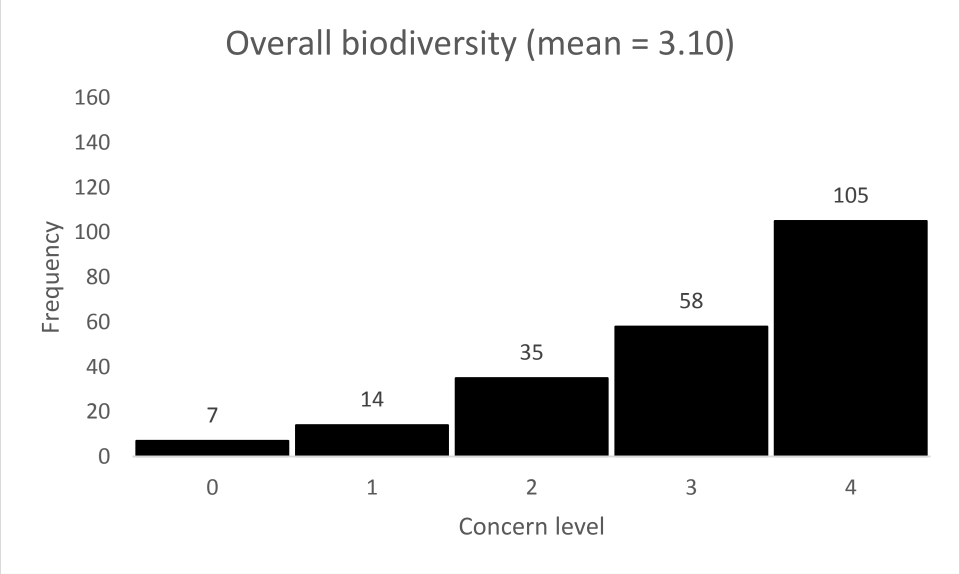


Figure 5: Survey results for "streambank stability (erosion)"

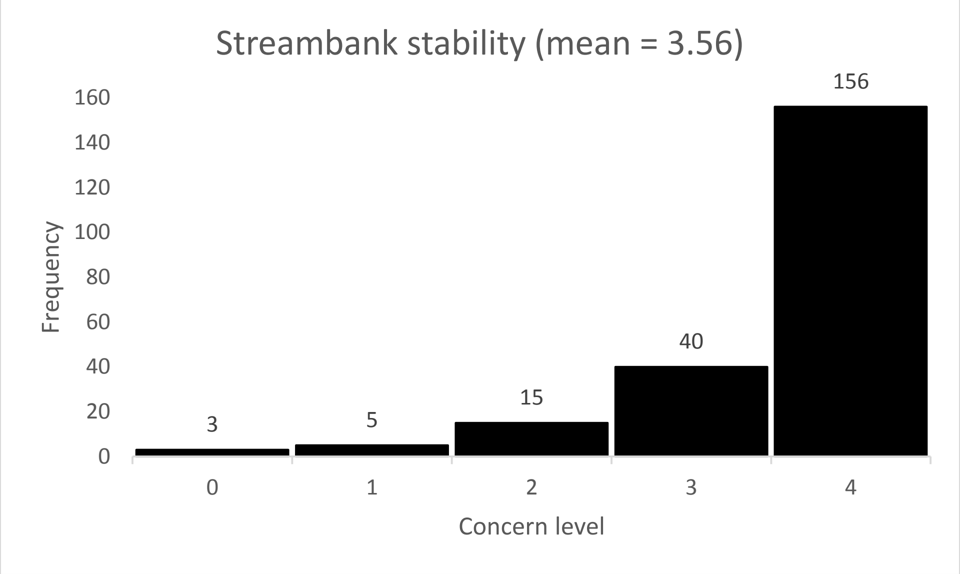


Figure 6: Survey results for "salmon/fish stocks"

Table 1: Summary table for survey results

Environmental Feature	Mean	Percentage answering “4”	Positive outliers	Negative outliers
Local environment in general	3.23	54.3%	----	----
Native plant community health	3.10	44.1%	0.02	0.03
Overall biodiversity	3.10	47.7%	0.00	0.05
Tree seedling growth/survival	3.05	46.1%	0.02	0.10
Streambank stability (erosion)	3.56	70.9%	0.13	0.01
Salmon/fish stocks	3.36	62.3%	0.08	0.07

The survey results suggest a pointed hierarchy of landowner concerns. “Streambank stability (erosion)” represents the greatest concern for landowners by a significant margin, followed by “salmon/fish stocks.” The remaining environmental features all fall in a similar range a little below the baseline concern for the “local environment in general.” The positive outliers reflect a similar hierarchy. However, the negative outliers depart from the mean hierarchy by suggesting “salmon/fish stocks” as the second most divisive issue after “tree seedling growth/survival.” The percentage of landowners answering “4: significant concern” aligns with the trends we see in the mean results. This alignment suggests that we can safely discuss the mean results without coming to wrong conclusions due to flawed assumptions that the distance between scores is uniform.

The ordinal regression does not suggest a strong relationship between concern for the “local environment in general” and the other environmental features. However, a directional trend is still apparent. The R^2(U) progresses as follows: native plant community health (0.30); overall biodiversity (0.27); salmon/fish stocks (0.20), streambank stability (erosion) (0.16); and finally, tree seedling growth/survival (0.15). These results suggest that concern for native plant community health and overall biodiversity are the most dependent on an underlying concern for the local environment in general, whereas concern for streambank stability (erosion) and tree seedling growth/survival are the least dependent on the underlying concern.

Chapter 6: Discussion of survey results

These survey results point to several important conclusions around *whether landowners express greater concern for environmental features relating to either ecosystem services or ecosystem integrity.* Most notably, landowners expressed the greatest concern for “streambank stability (erosion)” (3.56), including a 0.33 difference over the baseline concern for the “local environment in general” (3.23). Almost all of these landowner properties exist along waterways, so streambank stability represents an easily understood ecosystem service for the landowners. The next greatest feature of concern, “salmon/fish stocks” (3.36), is also easily understood as an ecosystem service.

The difference in concern for streambank stability and salmon/fish provides some nuance to the discussion around how an ecosystem service is easily understood. Both of these features closely relate to ecosystem services, however streambank stability likely relates more directly and universally to these landowners than salmon/fish do. Concern for salmon/fish requires some external valuing of issues like recreational/commercial fishing, culinary enjoyment, or the cultural significance of salmon. On the other hand, streambank stability carries implicit value for many of these landowners who own property next to active waterways. It follows that not only must landowners understand the ecosystem service, but that the service must relate to their own sets of values and concerns. In other words, a person might understand an ecosystem service's value for society (salmon/fish), but they're probably more concerned about the ecosystem services that relate directly to themselves (streambank stability).

In contrast, "native plant community health" (3.10) and "overall biodiversity" (3.10) are not closely related to ecosystem services. This distinction is not to say that these environmental features do not contribute to many ecosystem services, only that the connections are less obvious to members of the public. The barrier of understanding for landowners to appreciate how these features contribute to ecosystem services requires a significant ecological knowledge base. Landowners might intuit some value from these features, but they're less likely understand how that value relates to themselves. As another factor which might contribute to the lack of concern, these concepts are abstract and somewhat vague - unlike streambank stability (3.56) and salmon/fish (3.36), which are concrete and relatable. Native plants and biodiversity elicited even less concern from landowners than the "local environment in general" (3.23).

Adding further nuance to this discussion is the lack of concern for "tree seedling growth/survival" (3.05). Similar to streambank stability and salmon/fish, tree seedlings are a concrete environmental feature, but they did not elicit anywhere near the same level concern. This discrepancy further illuminates the role of relatability in landowner concern for ecosystem services. Tree seedlings are not easily relatable for delivering an ecosystem service unless the landowner harvests their property for timber. It follows that a feature's concrete nature can only act as a complementary component for assisting with understanding. A feature being concrete is not enough to elicit widespread concern on its own merits.

These results support my stated hypothesis that landowners express greater concern for environmental features more closely related to ecosystem services over ecosystem integrity. The nuance of these results expand on how environmental features can be easily understood, rather than saddling this conclusion with qualifiers and exceptions. For example, the discrepancy in concern between streambank stability (3.56), salmon/fish (3.36), and tree seedlings (3.05) demonstrates greater concern for features that are easily understood as *directly relating to oneself.*

The outlier analysis highlights some interesting trends for individual environmental features. First, the outlier analysis further demonstrates streambank stability as the feature of greatest concern. Streambank stability registered the highest positive outlier degree (0.13) and the lowest negative outlier degree (0.01). In other words, streambank stability stands out as a feature of concern for the most landowners, while simultaneously representing the least divisive feature for everyone else. Concern for streambank stability is probably even more noteworthy than the data suggests once you consider the anecdotal evidence of the incomplete surveys. Out of the 24 incomplete surveys, five landowners circled *nothing else* except a 4 (significant concern) for streambank stability. These landowners did not complete the survey, so we cannot know for certain their concern for the other features, but we can say conclusively that they care a great deal about streambank stability. It's probably a safe assumption that if these landowners declined to register concern for anything except streambank stability (at a 4), then the remaining environmental features likely would not score as high, and perhaps by a significant margin with lots of 0-2 scores. Such responses would increase the positive outlier degree for streambank stability (0.13) even further over the other features.

The outlier analysis revealed somewhat mundane results for native plants, biodiversity, and tree seedlings. Tree seedlings scored the highest for negative outliers (0.10). However, this result could be interpreted more as extreme apathy or confusion, instead of heightened divisiveness. It’s difficult to understand why people might have a heightened negative response to tree seedlings. It seems more likely that people just don’t know how to feel about tree seedlings, and therefore express lower concern for them. In contrast, the negative outlier degree for biodiversity (0.05) could be a backlash of sorts against environmentalism because much-hated environmental regulations often cite biodiversity as a key reason for the government intervention.

The most noteworthy results from the outlier analysis show an unfortunate divisiveness around salmon/fish. While it scored the second highest for positive outlier degree (0.08), it also scored the second highest for negative outlier degree (0.07). Many people in the Pacific Northwest strongly support efforts to save and restore wild salmon/fish populations. However, many other people view salmon/fish protection as a burden on the economy and an infringement on landowner rights to develop their property however they see fit. For example, most counties require fencing on pastures to prevent cows from accessing rivers and disrupting salmon spawning. Landowners might therefore understandably view salmon as a burden on their farming practices.

Also, landowners might simply dismiss salmon as a concern because no salmon spawn along their stretch of the river. Upstream landowners can be important for knotweed control because the plant aggressively spreads downstream, but the landowners might have more trouble understanding why they need to control the knotweed for salmon habitat if no salmon spawn where their property exists. The incomplete surveys further suggest confusion around the subject of salmon. Out of 24 incomplete surveys, ten landowners registered a response for *every other environmental feature,* except for salmon/fish, exclusively. One of these landowners explicitly wrote that “none (salmon) live above SF falls.” As in, the landowner does not understand why they should be concerned about salmon and therefore did not register an answer.

The ordinal regression analysis did not reveal any strong correlations between an underlying concern for the local environment and the other environmental features. However, a directional trend suggests that some features are less dependent on an underlying concern than others. Native plants (0.30) and biodiversity (0.27) were the most dependent features, and this greater relative dependence speaks to the need for higher ecological literacy to value these environmental features highly. On the other hand, streambank stability’s lower correlation (0.16) suggests a lesser dependence on ecological literacy to elicit concern. Tree seedlings represented the least correlated feature (0.15), which might suggest greater concern from the less ecologically literate, despite its low overall mean concern (3.05).

Knotweed and Ecosystem Services

Chapter 7: How knotweed invasion affects environmental features

Before we can apply the landowner survey results to developing more effective outreach strategies, we must first understand how knotweed affects ecosystem services. Effective outreach should balance what is persuasive (i.e., the landowner survey) and what is supported by scientific theory (i.e., the following analysis). For example, saying that knotweed is poisonous to people would probably elicit marked concern, but that statement is false and should therefore not appear in outreach materials. The following analysis provides the academic counterpoint of knotweed impacts to weigh against the landowner survey suggesting what is most persuasive. On its own merits, the following analysis aims to answer one of the central questions of this thesis, *how knotweed invasion affects ecosystem services, based on the existing scholarship?*

Analyzing how knotweed affects ecosystem services is not a straightforward endeavor. To date, the knotweed literature draws very few direct conclusions about how knotweed affects ecosystem services. Most often, the literature describes how knotweed invasion affects environmental features, which in turn connect to certain ecosystem services. For example, Urgenson et al. (2012) measured knotweed's negative impacts on native tree recruitment; which affect ecosystem services in the form of timber, promoting fish habitat, and preventing erosion. In other words, how knotweed affects ecosystem services rarely occurs across direct interactions, but is rather distributed across several interactions to varying degrees of impact. Further, these effects can overlap and compound or disperse. Such an analysis will be prone to devolving into a muddled mess.

In response, this thesis employs several organization strategies to maintain analysis clarity. First, I examine how knotweed affects various environmental features, without considering ecosystem services. Specifically, this thesis examines how knotweed affects seven environmental features: erosion, freshwater resources, trees, biodiversity, fish, climate, and pollination. It's important to establish these environmental effects first, because many ecosystem services draw influence from several different features.

This thesis next considers how those broader environmental impacts affect specific ecosystem services using The Millennium Ecosystem Assessment (MA) framework. The United Nations developed this framework in the early 2000's for a global assessment of the benefits garnered by humanity from various ecosystem features. This global assessment helped establish the importance of ecosystem services for human well-being. This section will be the point where the ecosystem features of the first section and the confidence assessment of the second section are applied directly to different ecosystem services outlined in the MA.

How knotweed affects erosion

Conservation groups overwhelmingly agree about knotweed's negative impacts on streambank erosion, despite a total absence of academic verification. This confidence derives from a basic understanding of knotweed's life history, in that knotweed senesces all aboveground biomass during the rainiest winter months. In other words, knotweed dies back completely during winter so there's nothing left above ground to prevent rain and flooding from washing away topsoil. While this basic understanding of how knotweed contributes to erosion is quite straightforward and intuitive, a more nuanced examination of the specific interactions reveals more specific erosion effects.

Specifically, knotweed's impacts on erosion are likely very different depending on where it's growing. Here, soil exposure plays the most critical role in creating erosion as micro-impacts from raindrops dislodge soil particles that are then washed away. Thus, soil exposure leads directly to soil erosion during rainy months. Despite a total lack of aboveground biomass, knotweed produces an extremely dense leaf litter that probably prevents direct soil exposure in upland areas.

Where knotweed most causes erosion is on streambanks, and especially streambanks with intense flooding. Again, this effect derives from knotweed's annual senescence during the rainiest winter months. Where flooding occurs, woody plants play an important role slowing down the current on the streambanks (Darby, 1999). Without woody plants to slow down the current, floods are free to scour away streambanks. In the months following the first flood event of the year, runoff erosion is also no longer mitigated by the dense leaf litter that will have been washed away in the flood.

While knotweed invasion leaves streambanks exposed to high-velocity floods, there are also several important dynamics that might limit the erosion effect. For one, knotweed retains its extensive and vigorous root system during the rainy winter months. Therefore, knotweed roots probably help hold together eroding streambanks. For another, woody plants can increase localized erosion as they create turbulence in their immediate vicinity. While woody plants can cause increased local erosion, there's still ample reason to believe that knotweed creates greater erosion due to the increase in flood velocity over a longer stretch of the waterway.

Knotweed's net effect on streambank erosion remains unknown. Conservation groups remain nearly unanimous in citing knotweed's impacts on creating erosion, but this claim remains unverified by any peer-reviewed literature. Researchers could examine knotweed root strength to reach a more certain conclusion about how well knotweed roots stabilize a streambank, in comparison to native plants. It could be that knotweed roots break apart more easily than native plants, thus limiting its stabilizing effect on the streambank. A more direct approach to measuring knotweed's effects on erosion could simply compare erosion rates on knotweed invaded banks to native plant inhabited banks on the same waterway. In conclusion, knotweed's effects on erosion remain unverified but knotweed's annual senescence does suggest the potential for damaging streambank erosion.

How knotweed affects trees

Knotweed demonstrates powerful effects on a wide range of tree species. Specifically, Urgenson et al. (2012) examined how knotweed presence affected tree seedlings in comparison to paired study plots without knotweed present. The researchers differentiated the seedlings by their successional phase: with one early succession, one mid succession, and one late succession species. Most impacted were the subject early-succession tree species, Red alder (*Alnus rubra*), and late-succession tree species, Western hemlock (*Tsuga heterophylla*): both exhibiting diminished survival and growth.

Knotweed effects on the subject mid-succession species, Sitka spruce (*Picea sitchensis*), were less significant but still noteworthy.

Knotweed's effects on these different tree species can in turn be linked to different competitive mechanisms (Urgenson et al., 2012). Perhaps most notably, knotweed hoarding of available sunlight imposed an 83% drop in Red alder survival. The authors link this drop in alder survival to light limitations by measuring the light levels above both the dead alders and the surviving alders: light levels above the surviving alders were 79% higher than above the dead alders. Urgenson et al. (2012) suggest that these surviving alders were simply lucky enough to be growing up through breaks in the knotweed canopy.

As an early succession tree species, alders are known to be shade-intolerant (Minore, 1979), so these findings around reduced alder survival from knotweed imposed light limitations are not surprising. Knotweed imposes these light limitations through an extremely dense leaf canopy that prevents light-limited plants like alders from growing up from underneath (Vanderklein et al., 2014). In other words, knotweed can effectively kill off any light limited tree species that hasn't grown tall enough to escape the knotweed imposed light limitations.

In contrast to the light limiting impacts on early succession trees like alders, Urgenson et al. (2012) link knotweed's effects on the late succession Western hemlock to below ground influence. For hemlock, knotweed presence reduced survival by 24%; and perhaps more indicative, reduced hemlock height growth by 122%. Light levels were not found to have any effect on the hemlocks but ectomycorrhizal (ECM) colonization dropped by 64% on surviving hemlock seedlings in knotweed test plots. ECM provide a critical function late succession trees like hemlock in fixing nitrogen, a limiting nutrient, into a usable form that helps the trees grow. With such a dramatic reduction in ECM colonization, the greatly reduced hemlock growth is a logical finding. Further complementing this finding, late succession tree species generally demonstrate heightened sensitivity to soil conditions (Christy, 1986; Minore, 1979). Therefore, late succession tree seedlings understandably struggle to grow within knotweed stands.

How knotweed affects freshwater resources

Only a single study has explicitly examined how knotweed might affect water availability. Vanderklein et al. (2013) examined the water use of a Japanese knotweed infestation along with a small creek in New Jersey. The study found that the knotweed patch consumed about 10.4 liters of water per day for each m^2 of ground cover (Vanderklein et al., 2013). This rate of water use is comparatively greater than rates measured in native willow and similar to rates found in native cottonwood trees (Nagler et al., 2003). A similar rate of water use for Japanese knotweed in comparison to cottonwood trees is significant because cottonwood trees grow several times taller than a Japanese knotweed patch. In other words, a taller plant would seem to suggest greater water use, as in the case of cottonwood and willow, but Japanese knotweed water use compares to a much larger cottonwood tree anyway. As a plant that can grow more up to 8 cm per day (Seimens & Blossey, 2007) and absorb nutrients at an extremely high rate (Urgenson et al., 2009), Vanderklein et al.'s (2013) findings around intensive knotweed water use should come as little surprise.

How knotweed affects fish

How knotweed invasion affects fish populations represents the most important knotweed-ES interaction. Fish provide many essential ES in their own right, and there's ample evidence pointing to how knotweed could affect fish habitat. While knotweed could affect myriad freshwater fish species, this thesis will focus on how knotweed could affect different salmon populations as a representative case study. Salmon serve as a helpful case study for four reasons: 1) salmon epitomize an ecosystem keystone species with heavy dependence on overarching ecosystem health, while also reciprocating critical inputs back into the ecosystem (Helfield & Naiman, 2006); 2) salmon further represent a cultural keystone species with significant societal value associated with them (Garibaldi & Turner, 2004); 3) many salmon populations are declining despite significant restoration efforts so identifying the driving forces behind these declines should help to reverse this trend; and 4) the existing salmon habitat literature is extensive, which should allow higher certainty linkages between knotweed invasion and fish habitat.

Knotweed impacts on fish combine from the previously discussed impacts regarding increased erosion, tree seedling suppression, and intensive water use. Bank erosion increases fine sediment loading through direct sediment inputs. Sediment loading is a well-studied detriment to salmon spawning success due to impairing dissolved oxygen circulation and entrapping emerging fry (Scrivener & Brownlee, 1989; Chapman, 1988). In simple terms, sediment loading from bank erosion can make the water turbid and suffocating.

Knotweed suppressing tree seedling recruitment threatens salmon habitat because trees play several critical roles in the creation of such habitat. First, trees that fall into waterways create large woody debris (LWD) structures that greatly benefit salmon. Generally speaking, LWD creates more complex river geomorphological features that salmon thrive in (Abbe & Montgomery, 1996; Fetherston et al., 1995). More specifically, pools form around LWD where salmon can escape the stronger flows of the main channel (Fausch, 1984), find cooler waters (Hartman et al., 1996), and hide from predators (Harvey & Stewart, 1991). Further, LWD fosters invertebrate communities, which are a critical food source for juvenile salmon (Wallace et al., 1995). For spawning habitat, LWD significantly improves the collection of critical spawning gravels (House & Boehne,1986). Perhaps most telling, researchers have closely correlated LWD density with juvenile salmon density (Fausch & Northcote, 1992; Roni & Quinn, 2001). In summary, LWD inputs are not a luxury for salmon but a critical component to their spawning and rearing habitat.

In addition, knotweed suppressing tree recruitment contributes to higher summer water temperatures that can stress or kill salmon. Trees help prevent dangerous water temperatures through one simple mechanism: shade (Beschta et al., 1987). Without trees to provide shade, most salmon species are not well adapted to higher water temperatures (McCullough, 1999). For instance, Sockeye salmon (*Oncorhynchus nerka*) show signs of stress in waters above 20^{o} C (Gilhousen, 1990) and can die in waters above 24^{o} C (Servizi & Jensen, 1977; Naughton et al., 2005). Higher water temperatures also increase disease susceptibility, inhibit behavior, alter the developmental timing, and drive higher energetic costs (Crozier et al., 2007; McCullough, 1999). Though mostly detrimental, it should be noted that higher water temperatures that remain within optimal ranges can improve development rates and increase food availability (Hartman et al., 1996; Hicks et al., 1991). In summary, higher water temperatures most often have a negative effect on salmon.

Knotweed might also generate higher water temperatures through intensive water use. Knotweed water use that lowers a stream's baseflow (Vanderklein et al., 2014) would create conditions for rising water temperatures through one simple mechanism: less water heats up faster than more water (Beschta et al., 1987). In combination, knotweed tree suppression causing less shade and knotweed water use causing less water, strongly suggest that knotweed invasion creates conditions for rising water temperatures that are detrimental to salmon.

As an important consideration for knotweed's effects on stream temperatures, many waterways already demonstrate high water temperatures through damaging land use practices and ongoing climate change. For land use, loggings along stream corridors provided the impetus for many of the research papers cited in this section that examine the effects of higher water temperatures on salmon. Today, laws in many states require loggers to leave habitat buffers along riparian corridors specifically for shading purposes (May et al., 1999). Where logging has stripped a stream's shading canopy, knotweed invasion would directly suppress the regrowth of this critical habitat feature. Also, climate change will probably amplify knotweed's effects on increased water temperatures. Longer, hotter summers will increase the incoming heat-forcing on a waterway; and less snowfall will decrease the spring runoff to lower baseflows even further (IPCC, 2014; Crozier et al., 2007). In simple terms, knotweed invasion compounds the problems with water temperatures already created by damaging land use practices and a warming climate.

Finally, independent of previously discussed impacts on salmon, knotweed invasion might disrupt food availability for juvenile salmon. Juvenile salmon depend on macroinvertebrate communities in freshwater environments for sustained growth. Researchers in Europe found that invading knotweed reduced macroinvertebrate biomass by 40% (Gerber et al., 2007). Such a stark reduction in macroinvertebrate biomass would have a profound and damaging impact on juvenile salmon feeding on those invertebrates. However, researchers in the Pacific Northwest has less conclusive impacts on macroinvertebrates (Cleason et al., 2013). Overall, knotweed shows a strong potential to disrupt food-webs that juvenile salmon depend on, but this disruption might also be situationally variable depending on the native ecosystem (Cleason et al., 2013; Gerber et al., 2007; Sibert et al., 1977).

How knotweed affects climate

Tamura & Tharayil (2015) found knotweed invaded sites demonstrated 26% higher soil C levels than adjacent non-invaded sites. However, this C sequestration was offset to a significant degree because the proportion C resistant to oxidation in knotweed-invaded soils was 21% lower. In other words, knotweed-invaded soils sequester more C than non-invaded soils, but the C is also more likely to reenter the atmosphere through oxidation.

While soil C sequestration produces a net benefit in knotweed-invaded areas, in-plant C sequestration must also factor into knotweed’s overall effect on climate. Unfortunately, scholarship has not further examined knotweed’s in-plant C levels, but we can draw some conclusions based on biomass. The majority of knotweed’s biomass lies underground in its extensive root system. If a knotweed-invaded site suppresses tree recruitment (Urgenson et al., 2012), then overall biomass would almost certainly measure well-below a forested area. Therefore, overall knotweed C sequestration likely measures similar to non-invaded areas when considering all factors.

How knotweed affects pollination

Knotweed likely benefits honey production due to its abundant nectar supply. Knotweed honey is well-recognized by the bee-keeping community. However, we must also consider possible complicating factors. For instance, the concentrated and abundant supply of nectar found in knotweed monocultures might lead pollinators to neglect pollinating certain native plants. Also, a benefit to bee populations would imply nectar supply to be a limiting factor in hive growth and health. Much has been made of beehive decline in recent years, but evidence primarily points to other environmental factors leading to widespread colony collapse disorder (Cox-Foster, 2007). If anything, the substantial concern over honey bee decline stems from an overabundance of plants to pollinate and not enough bees to pollinate them. On the other hand, quickly removing a large patch of knotweed that a colony is dependent upon for honey production could indeed produce a nectar shortage if the colony cannot adapt quickly enough to pollinating other plants in the area.

Chapter 8: How knotweed invasion affects specific ecosystem services

I will now analyze these knotweed impacts on water resources, fish, climate, and pollinators using the Millennium Ecosystem Assessment Framework. Effects on each ecosystem service will be considered independently for knotweed invasion and knotweed removal. The effects of knotweed invasion will compare to a historical ecosystem state. Where relevant, this analysis will also consider how knotweed removal might affect the ecosystem service, either with or without active restoration practices.

Provisioning: fish

For fish populations, the existing knotweed literature suggests widespread and damaging impacts from invasion. While researchers have not yet directly measured knotweed's impact on fish populations, numerous studies point to certain ecosystem impacts, which in turn have a demonstrable negative effect on fish populations. For example, knotweed's suppression of tree recruitment (Urgenson et al., 2012) suggests long-term negative impacts for spawning salmon that rely on trees for shade (Beschta et al., 1987) and habitat-forming LWD inputs (Abbe & Montgomery, 1996; Fetherston et al., 1995). This link alone, between knotweed tree-suppression and the important habitat features that trees provide, is enough to suggest significant negative impacts with high certainty. In addition, knotweed may further disrupt fish habitat through extreme water uptake (Vanderklein et al., 2014) and food web disruption (Gerber et al., 2007).

Wild fish provide a sustainable food source and significant economic input for many communities affected by knotweed invasion. For instance, the Wild Salmon Center indicate that "Pacific salmon fuel a $3 billion industry, supporting tens of thousands of jobs…" (WSC website). With knotweed invading many of the rivers that these salmon depend on across the West Coast, the dire implications for such an important natural provision are clear. Even a small decline in salmon productivity would greatly impact the communities that depend on them. With salmon populations already struggling at a fraction of their historic levels due to over-fishing, habitat destruction, and pollution, additional impacts from knotweed invasion can scarcely be afforded. Looking forward, knotweed invasion threatens to amplify the projected impacts of climate change, with shade becoming ever more important for keeping stream temperatures cool enough for salmon to survive.

In response, many state agencies have committed substantial resources toward knotweed control for the express purpose of salmon habitat restoration. Unfortunately, the ultimate habitat benefits of knotweed removal are not guaranteed. Claeson and Bisson (2013) found that sun exposure played an important role in what plants established themselves where the knotweed was removed. On smaller waterways with extensive tree cover, passive restoration proved effective with native plants dominating the regrowth. However, on larger rivers with more sun exposure, invasive plants such as blackberry often outcompeted the native plants. These findings align with the general academic consensus that native plants are more successful in competition with invasive plants in shadier locations. Therefore, on larger rivers with extensive sun exposure, conservation groups should engage in native planting activities following knotweed removal in order to better assure a positive habitat effect for fish following knotweed removal.

Provisioning: honey

Knotweed honey has become a popular nectar source for many beekeepers. The plant's concentrated and abundant flowers fuel rapid honey production. Further, knotweed flowers bloom in the late summer when most other plants have already finished blooming. This late emergence of a prominent nectar source allows beekeepers to continue harvesting honey much longer than they would be able to otherwise. For honey production, knotweed invasion can be viewed as a high-certainty positive development, with knotweed removal generating a high-certainty negative development for beekeepers.

Balancing this positive ecosystem service against knotweed's numerous negative effects is easier than one might expect, however. The majority of knotweed's negative effects concentrate within riparian corridors where the plant spreads most aggressively and degrades fish habitat. Outside of riparian corridors, knotweed still spreads and creates some negative effects, but nowhere near the pace and scale as within riparian corridors. Accordingly, knotweed control groups prioritize knotweed removal within riparian areas. Inevitably limited funding and a short treatment season leave few resources for addressing non-riparian knotweed infestations. In other words, knotweed is likely a permanent feature on our landscape, where it can be appreciated for its contributions to honey production where it grows outside of riparian corridors.

Provisioning: freshwater

Knotweed's effects on freshwater availability remain uncertain. Vanderkelein et al. (2014) are the only researchers to have studied this subject to date. Knotweed's water-uptake was sufficient to lower the adjacent stream. However, the effect size was similar to native plants such as willow or cottonwood. Given the limited existing research, knotweed's water-uptake is best understood as a net-neutral impact on freshwater availability in comparison to native plants. Better research on this subject would allow for more conclusive statements.

Provisioning: medicines

Knotweed is a common ingredient in several traditional Chinese medicines (Wu et al., 2013). While not widely known or recognized for this purpose in many of the regions that knotweed has invaded, there's at least potential for medicinal use. As with honey, non-riparian knotweed infestations should easily satisfy knotweed demand for this purpose.

Regulating: climate

Knotweed's effects on climate remain understudied. The one existing study on the subject indicates a net-neutral effect in comparison to native soils. Knotweed soils seem to sequester C more rapidly, but that positive effect is offset by a greater tendency for the C to re-oxidize back into the atmosphere (Tamura & Tharayil, 2015). Overall, knotweed's effects on climate are probably not significant enough to warrant inclusion into decision-making processes.

Regulating: flood control

Knotweed's impacts on ecohydrology remain its most understudied aspect – especially considering its propensity to spread in riparian areas. Knotweed's impacts on flooding have drawn speculation from several sources, but to date, no studies have examined its effects more closely. For instance, Edwards & Howell (1989) suggest that "its form could increase the risk of flooding in some river systems through the *increase* in frictional resistance to water flow" (p. 222). I do not see any evidence for this conclusion though. In fact, I see evidence to the contrary – that knotweed invasion likely decreases risk of flooding based on a *decrease* in "frictional resistance to water flow." To clarify, "frictional resistance to water flow" refers to a phenomenon where woody plants slow the water during high flows events, which encourages lateral spreading (aka flooding). Knotweed senesces all of its above-ground biomass during rainier winter months, which would actually *decrease* frictional resistance in comparison to native woody plants that retain an above-ground presence during the winter. In summary, knotweed's growth form likely decreases local flooding due to its non-existent above-ground presence during rainier winter months.

Curiously, other sources suggest that knotweed might increase flooding for exactly the opposite reason. For example, the IUCN indicates that knotweed may, "increase the risk of flooding and river bank erosion as it establishes monospecific stands that die back in the winter leaving banks exposed" (Invasive Species Specialist Group, 2016). On a larger spatial scale, this claim could indeed be true. Without frictional resistance to impede high-flow events, water rushes downstream in larger volumes. If frictional resistance presents itself in greater mass further downstream, upstream knotweed infestations could indeed increase downstream flooding as higher water volumes slow on the downstream woody plants and spread laterally.

In summary, knotweed invasion unquestionably *decreases* frictional resistance because it leaves riverbanks exposed during rainy winter months. This effect should always decrease local flooding, but it could also increase downstream flooding if more woody plants exist along those downstream reaches. Despite somewhat contradictory and confusing claims from other sources, I am confident in my assessment of knotweed's impacts on flooding. My confidence stems from the easily understood effects of frictional resistance: as frictional resistance goes up, so does local flooding; as frictional resistance goes down, flow velocity goes up (increasing downstream water volume). Knotweed's effects on flooding follow a simple extrapolation from the fact that knotweed presents effectively zero frictional resistance during rainy winter months. While I am confident in my conclusions, more targeted research would undoubtedly help clarify knotweed's effects on flooding.

Regulating: erosion control

As with flood control, no studies have examined knotweed's effects on erosion. But yet again there are important conclusions to be drawn from a basic understanding of knotweed's growth form. Where knotweed's overall effects on flooding are situational depending on downstream woody plant presence, knotweed's effects on erosion are more certainly damaging in most instances, both locally and downstream. Locally, exposed riverbanks during rainy winter months allow high-flow events to carve away riverbanks that might otherwise be protected by native woody plants. Knotweed's extensive root system does provide some structure in the soil, but the net effect is almost certainly increased erosion when compared to riverbanks occupied by woody plants. Downstream, the increased flow velocity, caused by knotweed's non-existent frictional resistance, would lead to increased erosion, even with a greater woody plant presence. While it can be stated with high certainty that knotweed increases erosion, the need for research stems from a question of degree: how much does knotweed increase erosion? This question remains completely unanswered.

There's also a high certainty that removing knotweed will help reduce erosion, even without any active restoration of native plants. Other common riparian invaders, such as Reed Canary Grass or blackberry, maintain an above ground presence during rainier winter months. Native plants are always preferable, but it’s worth noting the certainty of benefit for bank stability from knotweed removal.

Regulating: water quality

Several different high-certainty can be extrapolated to conclude a negative effect on water quality. First, knotweed’s suppression of tree recruitment (Urgenson et al., 2014) will eventually increase water temperatures due to diminished shading (Beschta et al., 1987). Higher water temperatures are a well-known factor for increased microbial reproduction that potentially spreads disease. Second, knotweed’s effects on erosion would also decrease water quality as more sediment is carried in the streamflow. While any impact on water quality is important, these impacts are probably not very severe.

Unfortunately, knotweed removal does present some risks to water quality because herbicides represent the only viable control option for larger infestations. The most commonly used herbicide for knotweed treatments is imazapyr. This herbicide is approved for use in aquatic environments because of its extremely low toxicity rating. Patten (2003) tested imazapyr’s effect on juvenile Chinook salmon at extremely high concentrations with no visible impact on fish survival. Important for knotweed treatments, the herbicide mix needs only a 1% imazapyr concentration for effective control, which should greatly limit the amount of imazapyr entering a waterway. Further, imazapyr quickly degrades in aquatic environments (Patten, 2003). In light of imazapyr’s low toxicity, rapid degradation, and high treatment effectiveness at low concentrations, its use for controlling a damaging invader such as knotweed is well justified. While no notable impacts on water quality are currently known from imazapyr use, it’s still important to consider as a foreign chemical entering a freshwater system.

Regulating: biological control

Biological control refers to an ecosystem’s ability to naturally control and limit the spread of pest species. As a pest itself, knotweed inherently undermines this ecosystem service. Many gardeners struggle to control knotweed infestations and often don’t receive any assistance from control groups unless they’re located on a priority waterway. That said, other landowners might appreciate knotweed for either its ascetics or its nectar availability for local bee colonies. Such positive sentiments toward knotweed are common in the United States but extremely rare in the United Kingdom. Awareness and concern about knotweed is much higher in the UK as many municipalities aggressively controlling it and fining landowners who have it on their properties. Some landowners even see their property values drop if there’s a knotweed infestation present.

Regulating: pollination

Bees serve an important ecosystem function as a pollinator of native plants and agricultural crops. As a favorite source of nectar for bees, knotweed could conceivably act as either a boost or a hindrance to this ecosystem service. If bees are pollinating knotweed at the exclusion of other plants, knotweed would be a hindrance. However, if this preference for knotweed is not exclusionary and knotweed’s nectar abundance helps colonies thrive, the net effect could still be positive with more bees pollinating the area. No research exists to help determine this balance.

Cultural: heritage

As a tool for understanding how knotweed might impact cultural heritage, we can use the concept of cultural keystone species. Garibaldi & Turner (2004) define cultural keystones as “culturally salient species that shape in a major way the cultural identity of a people, as reflected in the fundamental roles these species have in diet, materials, medicine, and/or spiritual practices.” These authors specifically cite Western Red Cedar (Thuja plicata) as a cultural keystone species for Native American tribes in the Pacific Northwest, where knotweed is currently invading. We know from Urgenson et al. (2014) that knotweed presence greatly limits the growth of late succession tree seedlings such as cedar. However, while knotweed certainly impacts cedar growth where it invades, its impacts do not likely extend to cultural degradation because cedar trees grow in many terrestrial habitats where knotweed struggles to invade.

The same cannot be said for salmon though. As previously discussed, knotweed aggressively invades waterways that salmon depend on for spawning and rearing. Its impacts on salmon are diverse and damaging. Salmon represent an important cultural symbol for Native American tribes. It would be devastating to their cultures to lose this cultural connection or see it degraded further. In addition to the value that Native cultures place on salmon, immigrant communities also cherish salmon as an icon of their region. For example, many cities in the Pacific Northwest host events to celebrate the returning of the salmon every year. In summary, knotweed clearly threatens to degrade the cultural heritage that salmon represent, especially in the Pacific Northwest region.

Cultural: sense of place

A sense of place refers to a community's recognition of the native ecosystem in a given region. Native communities hold this service in high regard, having lived here for centuries in a native ecosystem. Non-native communities do not typically place much emphasis on this type of ecosystem service, as exemplified by their introduction of many non-native plants for ornamental purposes. Even so, knotweed could disrupt any sense of place people have that's based on native plant characteristics. Knotweed's bamboo-like shoots do not resemble any native plants found in either Europe or North America.

Cultural: recreational fishing

As previously discussed, knotweed demonstrates several impacts that would degrade fish habitat. Degraded fish habitat would presumably extend to less productive fish stocks, and in turn, less rewarding recreational fishing. Recreational fishing is a valued past time for native and non-native communities alike. When degraded habitats fail to support productive fish stocks, tensions can arise when regulatory agencies need to limit the amount of fish taken. These unfortunate situations demonstrate the tremendous cultural value placed on recreational fishing.

Table 2: Summary of how knotweed affects ecosystem services

Negative impacts	**Positive impacts**	**Inconclusive/mixed**
Provisioning: fish	Provisioning: honey	Regulating: flood control
Provisioning: freshwater	Provisioning: medicine	Regulating: climate change
Regulating: erosion control		Regulating: pollination
Regulating: water quality		
Regulating: biological control		
Cultural: sense of place		
Cultural: recreational fishing		
Cultural: heritage		

Conclusion

Knotweed invasion is here to stay. Its widespread populations make eradication impossible, and its aggressive spreading along waterways degrades many important ecosystem functions. However, knotweed's linear spreading along waterways also offers an opportunity for meaningful control. If control groups can extirpate the plant from prominent waterways, it's unlikely to spread further and degrade terrestrial habitats. This opportunity for control comes with a substantial challenge: needing 100% landowner agreement to control the knotweed along the waterway. Without universal cooperation from landowners, the untreated knotweed will likely serve as a continual source population for downstream spreading.

This need for landowner cooperation highlights the importance of landowner outreach strategies for the success of knotweed control programs. Highly persuasive outreach materials will greatly accelerate knotweed control efforts as more landowners sign onto the control program. Upon nearing 100% landowner cooperation, persuasive outreach to the remaining holdout landowners could mean the difference between successful knotweed extirpation from the watershed and need to return on an annual basis to monitor and eliminate the new growth from downstream spreading. In sum, the importance of persuasive landowner outreach cannot be overstated for developing successful knotweed control programs.

This thesis hypothesized that ecosystem services provide a more persuasive model for landowner outreach than a science-based, ecosystem integrity model. The ecosystem services model represents an anthropocentric focus on the environment that helps people understand the benefits of different ecosystem features. Landowners should be more likely to sign onto knotweed control programs if they understand how knotweed invasion affects the environmental features that they care about. In contrast, an ecosystem integrity model focuses on environmental relationships that balance an ecosystem. This model is useful for identifying land management priorities to maintain ecosystem balance, but it can be opaque and confusing for anyone who isn't familiar with ecological relationships and balance. In other words, landowners need to understand the importance of controlling knotweed without diving into complex ecological relationships.

To test this hypothesis, I collaborated with King County Noxious Weed Control in Washington State to survey the landowners participating in their knotweed control program. This survey asked landowners to rate their level of concern for different environmental features. These environmental features were tailored to fit known impacts of knotweed invasion. The features also reflected either an ecosystem services model (salmon/fish stocks and streambank stability) or an ecosystem integrity model (native plant community health and overall biodiversity).

Survey results clearly supported the stated hypothesis that landowners would express greater concern for environmental features easily understood as ecosystem services. Landowners expressed the greatest concern for streambank stability (3.56) and the next greatest concern for salmon/fish (3.36). Landowners expressed lower concern for environmental features reflecting an ecosystem integrity model with native plants (3.10) and biodiversity (3.10) both rating below landowner baseline concern for the local environment in general (3.23).

These survey results carry important implications for landowner outreach strategies. Streambank stability clearly stands out as the most persuasive potential line of outreach. In addition to the survey results showing significant landowner concern for streambank stability (3.56), outreach materials can also easily explain how knotweed erodes away streambanks in simple and straightforward terms. Above ground knotweed shoots die back completely during the rainy winter months, leaving streambanks exposed to violent flood events. This simple explanation of how knotweed causes erosion probably also explains why knotweed researchers have not yet studied this subject – because the effect is so obvious and can be so easily understood. However, this omission from knotweed literature leaves knotweed control groups unable to relate any type of degree of erosion impact in either outreach or funding procurement efforts.

That said, the simple scientific reasoning behind knotweed causing erosion is still strong enough to support its inclusion in outreach materials. In the informal survey of easily accessible knotweed outreach materials, 15/20 brochures referenced erosion as an impact. While erosion impacts are already widely referenced, this thesis concludes that erosion impacts should be universally referenced in knotweed outreach materials. In the outreach materials that already reference erosion, this impact could be highlighted further and pushed to the forefront. Knotweed outreach of every sort should not pass up the opportunity to emphasize how knotweed invasion causes erosion along streambanks. Landowners will be highly receptive to this message and the scientific reasoning is simple and sound.

The next most persuasive impact of knotweed invasion, degrading salmon/fish habitat, introduces substantially more complexity for inclusion in outreach materials. To start, salmon/fish were definitely a point of concern for landowners (3.36), but not on the same level as streambank stability (3.56). Perhaps more important than the lower overall concern, salmon/fish garnered the second highest negative outlier degree (0.07). In other words, a relatively large number of landowners were either notably apathetic toward salmon/fish or held genuinely negative feelings toward them. Salmon especially have become a highly politicized issue in the Pacific Northwest, so while some landowners might jump at the opportunity to help restore salmon habitat, others might be repelled by referencing impacts on salmon. In sum, outreach materials referencing impacts on salmon represent a starker risk/reward tradeoff than all the other environmental features included in the survey.

Contributing to the uncertain grounds for inclusion of salmon/fish impacts in outreach materials is its more complex interactions creating those impacts. As discussed in ecosystem services section of this thesis, knotweed affects salmon in a myriad of ways through several different pathways. Is it enough to simply say that knotweed degrades salmon/fish habitat? Or do landowners require an understanding of the mechanisms for habitat degradation in order to register concern? The answer is unclear. However, a simple bridge of understanding could be constructed around the importance of trees for salmon habitat. Knotweed suppresses tree growth/survival (Urgenson et al., 2012), and trees provide critical shade and large woody debris that salmon depend on. We learned from the landowner survey that tree seedlings do not represent a point of concern on their own (3.05), but they could still serve a valuable explanatory role within the context of salmon habitat. It seems likely that the high negative outlier degree for tree seedlings (0.10) is more due to confusion than an outright objection. Explaining to landowner why trees are important for salmon could help remedy this confusion and the negative responses in turn.

In keeping with the risk/reward nature of including salmon/fish impacts, the outreach material is divided in its actual inclusion with 11/20 sampled brochures referencing this impact. Knotweed control groups could conduct more targeted surveys of their landowners to parse out if salmon can indeed represent a persuasive line of outreach. This thesis concludes that there’s enough scientific evidence and persuasive potential to include salmon/fish impacts in outreach materials. However, control groups should be wary to prevent a backlash against salmon/fish. The potential reward from its inclusion should not be overlooked, but the risk is also noteworthy enough to warrant close consideration.

How knotweed affects both streambank stability and salmon/fish habitat remain woefully understudied in the knotweed literature. This thesis used existing scientific research and widespread consensus in the knotweed control community to reason through the different ways in which knotweed might affect these environmental features. However, primary research is needed in order to validate and quantify these theories.

For native plants, this impact from knotweed invasion seems to hold limited persuasive potential (3.10). The subject has been widely studied and 19/20 knotweed brochures included relevant language. Native plants are a popular subject for both academic research and outreach materials because they relate most directly to knotweed's nature as an invasive plant. Its inclusion in outreach materials could be helpful for describing knotweed as an invasive plant, but landowners do not hold much implicit concern for native plants. In line with the stated hypothesis, native plants are not easily understood as an ecosystem service. It follows that native plants are a sensible inclusion in outreach materials, but should not be relied upon for persuasion.

Biodiversity represents an interesting subject for knotweed outreach. It has been widely studied but does not hold much persuasive potential (3.10). It also registered a relatively high negative outlier degree (0.05). However, 9/20 sampled knotweed brochures included relevant language and most of these used a clever device for its inclusion, by dropping the "bio" and only referencing "diversity" in the ecosystem. It's unclear whether this device effectively avoids the negative responses to biodiversity, but using "diversity" does seem preferable to "biodiversity", without losing much of its explanatory power.

Outside of the targeted discussion around knotweed outreach, this thesis sheds important light on the ecosystem services model more generally. This model originally came into being in response to the widely held belief that our natural systems were woefully undervalued in our economy if they were valued at all. Ecosystem services offered a foundation for economic analysis as a means of making the importance of the environment more relatable to people. In the years after the first Millennial Ecosystem Assessment was released in 2000, critics of this model pointed to the dangers of assigning monetary values to our environment in the first place. These critics assert that the environment holds implicit value that cannot, and should not, be diminished to a monetary figure.

This thesis avoids the usual heated debate around ecosystem services to consider the merits of an ecosystem services model, independent from any monetary valuation. This thesis scrapes away potentially flawed economic applications of ecosystem services to consider its core rhetorical value – making the environment more relatable to people. In a rhetorical capacity, the ecosystem services model appears to excel in the critical task of improving knotweed outreach strategies. These positive results could begin to redefine ecosystem services as an incredibly valuable rhetorical tool for public outreach first and foremost over any economic application. The positive results of this thesis should be carried forward toward testing the rhetorical potential of ecosystem services in other areas.

In closing, this thesis produced an important contribution to the knotweed literature and the ecosystem services literature more broadly. It began by exploring how theories of landowner outreach might apply to knotweed specifically. It used a statistically robust landowner survey to confirm its stated hypothesis that landowners express greater concern for environmental features relating to ecosystem services over ecosystem integrity. It examined the knotweed literature through the lens of ecosystem services and considered how knotweed invasion affects not-yet directly studied subjects such as erosion, flooding, and salmon. The conclusion of this thesis offered several suggestions for improving knotweed outreach materials and also began to redefine ecosystem services as a powerful rhetorical tool, instead of a flawed economic framework. I hope that this thesis genuinely helps inform better outreach strategies for my fellow weed-warriors and perhaps sparks additional research questions from my fellow students of the environment.

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Appendix A

Outreach brochure and website survey data

Native Plants	Biodiversity	Tree seedlings	Stream banks	Fish	Source
1	0	0	1	1	WA NWCB
1	0	0	1	1	King County
1	0	0	1	1	TNC
0	1	0	1	0	UW extension
1	0	0	1	1	Pierce Conservation District
1	0	0	1	1	SWCRPC
1	0	0	0	1	Coos Watershed Association
1	0	0	1	1	Luckiamute Watershed Council
1	0	0	1	1	Clallam County, WA
1	0	0	1	0	Clackamas County CD
1	1	0	1	1	Invasive Species Council, BC
1	1	0	1	0	Sullivan County CD
1	0	0	1	0	Delaware County CD
1	0	1	0	1	City of Cannon Beach
1	1	0	0	1	Forest Service, BC
1	1	0	0	0	Hawkeye CWMA
1	1	0	1	0	Sea Grant, PA
1	1	0	1	0	Golden Sands RCDC
1	1	0	1	0	New York Invasive Species
1	1	0	0	0	University of Maine

Corresponding source locations

Source	Website
WA NWCB	https://www.nwcb.wa.gov/pdfs/knotweed_brochure.pdf
King County	http://your.kingcounty.gov/dnrp/library/water-and-land/weeds/Brochures/knotweed-brochure.pdf
TNC	https://www.invasive.org/gist/products/outreach/knotweed-pnw.pdf
UW extension	http://clean-water.uwex.edu/pubs/pdf/knotweed.pdf
Pierce Conservation District	http://www.piercecountycd.org/DocumentCenter/View/104
SWCRPC	http://swcrpc.org/wp-content/uploads/2013/11/knotweed_final_unrotated.pdf
Coos Watershed Association	http://www.cooswatershed.org/wp-content/uploads/2017/01/CoosWA-knotweed-brochure.pdf
Luckiamute Watershed Council	http://www.luckiamutelwc.org/uploads/8/8/3/5/8835330/knotweed_brochure.pdf
Clallam County, WA	http://www.luckiamutelwc.org/uploads/8/8/3/5/8835330/knotweed_brochure.pdf
Clackamas County CD	https://conservationdistrict.org/?wpfb_dl=206
Invasive Species Council, BC	http://bcinvasives.ca/documents/Knotweeds_TIPS_Final_07_22_2016.pdf
Sullivan County CD	http://catskillstreams.org/pdfs/rondout_knotweed_bro.pdf
Delaware County CD	https://catskillstreams.org/pdfs/dcswcdknotweedbrochure.pdf
City of Cannon Beach	http://www.ci.cannon-beach.or.us/publicworks/page/knotweed-control-faqs
Forest Service, BC	https://www.for.gov.bc.ca/hra/plants/downloads/KNOTWEED.pdf
Hawkeye CWMA	http://www.mvr.usace.army.mil/Portals/48/docs/Recreation/ODC/InvSp/JapaneseKnotweedBRO.pdf
Sea Grant, PA	https://seagrant.psu.edu/sites/default/files/Japaneseknotweed2013_reduced_0.pdf
Golden Sands RCDC	https://www.uwsp.edu/cnr-ap/UWEXLakes/Documents/programs/CLMN/AISfactsheets/11JapaneseKnotweed.pdf
New York Invasive Species	http://www.nyis.info/index.php?action=invasive_detail&id=43
University of Maine	http://www.maine.gov/dacf/php/gotpests/weeds/factsheets/jap-knotweed-me.pdf

Appendix B

Landowner survey data

Survey #	Local environment	Native plants	Biodiversity	Tree seedlings	Stream banks	Salmon/fish
1	4	4	4	4	4	4
2	4	2	4	2	4	4
3	4	4	4	4	4	4
4	2	1	1	1	4	3
5	4	4	4	4	4	4
6	2	3	3	2	3	3
7	3	3	3	3	4	3
8	4	2	2	1	3	3
9	4	4	4	4	4	4
10	4	4	4	4	4	4
11	4	4	4	4	4	4
12	3	2	4	3	3	3
13	4	4	4	4	4	4
14	3	2	3	3	3	3
15	2	2	2	3	3	3
16	3	3	3	3	4	4
17	3	3	2	4	4	4
18	2	2	1	0	2	2
19	3	3	3	3	4	4
20	3	3	3	3	3	3
21	4	4	3	2	4	2
22	4	4	4	4	4	4
23	4	4	4	4	4	4
24	4	4	4	4	4	4
25	3	2	3	2	4	4
26	4	4	4	4	4	4
27	4	4	4	4	4	4
28	4	3	3	3	4	4
29	4	4	4	4	4	4
30	4	4	4	4	4	4
31	4	4	4	4	3	3
32	4	4	4	4	4	4
33	3	3	4	4	4	3
34	4	4	4	4	4	4
35	2	3	3	3	3	3
36	4	3	2	3	4	4
37	4	3	2	3	4	4
38	4	4	4	4	4	4
39	3	3	3	3	4	3
40	1	3	3	1	4	2
41	4	4	4	4	4	4
42	3	1	1	1	4	4
43	2	2	2	1	1	4
44	4	4	4	4	4	4
45	3	4	3	4	4	3
46	4	4	4	4	4	4
47	3	3	3	4	4	4
48	4	4	3	3	4	1
49	2	2	2	2	4	3
50	4	4	4	4	4	4
51	4	4	4	4	4	4
52	0	0	0	0	2	0
53	3	3	4	4	4	4

Survey #	Local environment	Native plants	Biodiversity	Tree seedlings	Stream banks	Salmon/fish
54	1	1	1	1	1	2
55	3	3	3	3	4	3
56	2	2	2	3	4	4
57	4	4	4	4	4	4
58	2	2	2	2	3	1
59	2	2	2	2	3	2
60	4	4	4	2	4	2
61	4	3	4	4	4	4
62	4	4	3	3	4	4
63	4	4	4	3	4	4
64	3	3	3	4	4	4
65	2	2	2	2	2	4
66	4	4	4	4	4	4
67	2	3	1	1	2	1
68	3	3	3	3	4	4
69	4	3	4	2	4	4
70	4	3	4	4	4	4
71	4	4	4	4	4	4
72	3	3	3	2	3	4
73	3	3	3	3	3	4
74	2	2	3	3	4	4
75	4	4	4	4	4	4
76	1	1	1	2	3	0
77	3	2	3	3	4	4
78	4	4	4	4	4	4
79	4	4	4	4	4	4
80	4	4	4	4	4	4
81	1	1	2	2	4	3
82	4	4	4	4	4	2
83	0	1	1	3	4	1
84	4	4	4	4	4	4
85	4	4	4	4	4	4
86	3	2	2	2	3	4
87	3	4	4	4	4	3
88	3	3	3	3	3	3
89	4	3	3	4	4	2
90	4	4	4	4	4	4
91	2	2	3	3	2	2
92	4	3	3	2	4	3
93	3	3	3	3	3	3
94	4	4	4	4	4	4
95	4	4	4	4	4	4
96	3	3	3	4	4	3
97	4	2	2	2	3	4
98	0	0	0	1	1	0
99	3	1	1	1	4	4
100	2	3	2	1	1	1
101	3	2	2	0	3	4
102	2	2	1	3	4	3
103	1	1	1	1	4	1
104	4	4	4	4	4	4
105	4	4	4	4	4	4
106	4	2	4	2	4	3
107	2	4	4	4	4	4
108	3	3	3	3	3	4
109	0	0	0	0	4	0

Survey #	Local environment	Native plants	Biodiversity	Tree seedlings	Stream banks	Salmon/fish
110	4	3	2	3	4	4
111	2	2	1	1	3	2
112	2	4	3	4	4	3
113	4	3	4	3	3	4
114	3	2	4	3	4	4
115	3	2	2	1	4	4
116	2	3	3	1	3	4
117	4	4	4	4	4	4
118	2	3	2	1	4	2
119	4	4	2	3	4	4
120	4	3	4	3	3	4
121	3	2	2	3	3	3
122	4	3	4	4	4	4
123	4	3	4	4	4	4
124	4	4	3	4	4	3
125	3	3	3	3	4	4
126	4	4	4	4	4	4
127	4	4	4	4	4	4
128	4	4	4	3	4	4
129	4	4	4	4	4	1
130	4	4	4	4	4	4
131	4	4	4	4	4	4
132	4	4	4	4	4	4
133	4	4	4	4	4	4
134	4	3	3	3	4	4
135	4	4	3	4	4	2
136	2	2	2	4	4	4
137	4	4	4	3	4	4
138	3	3	2	3	3	3
139	4	4	4	4	4	4
140	3	3	4	3	4	3
141	4	4	4	4	4	4
142	4	3	2	2	4	3
143	4	4	4	4	4	4
144	3	4	4	4	4	4
145	0	3	3	3	3	3
146	4	4	4	4	4	4
147	4	4	4	4	4	3
148	4	4	4	4	4	4
149	2	4	3	2	2	2
150	3	3	3	3	4	4
151	1	1	1	3	2	0
152	4	4	4	3	4	4
153	3	3	3	3	4	2
154	2	3	2	2	3	3
155	4	4	4	2	4	3
156	4	4	4	4	4	4
157	4	3	4	4	4	4
158	4	4	4	4	4	4
159	1	0	0	4	1	0
160	4	4	4	4	4	4
161	4	4	4	4	4	4
162	3	3	3	3	4	2
163	4	2	2	2	2	2
164	4	4	3	2	2	3

Survey #	Local environment	Native plants	Biodiversity	Tree seedlings	Stream banks	Salmon/fish
165	2	2	3	3	3	2
166	2	3	2	3	2	2
167	4	4	4	2	4	4
168	4	4	4	4	4	4
169	2	0	1	0	3	3
170	4	4	4	4	4	4
171	4	4	4	2	4	4
172	4	4	4	4	4	4
173	4	4	4	4	4	4
174	2	1	1	2	4	1
175	3	4	4	3	3	4
176	4	4	4	4	4	4
177	4	4	4	4	4	4
178	2	2	3	3	4	4
179	3	3	2	1	2	4
180	4	3	3	3	4	4
181	4	3	3	2	0	3
182	4	3	3	3	4	4
183	4	3	4	4	3	4
184	2	2	3	2	3	4
185	4	3	3	3	4	3
186	2	3	2	3	2	4
187	2	2	2	2	4	4
188	3	3	2	3	2	2
189	3	3	3	3	3	3
190	3	3	4	3	4	4
191	3	3	3	3	3	3
192	2	3	2	2	3	3
193	3	2	3	1	3	4
194	4	4	4	4	4	4
195	4	3	3	2	3	3
196	2	2	2	3	2	3
197	4	4	4	4	4	4
198	3	3	4	4	4	3
199	0	0	0	0	0	1
200	3	3	3	3	3	4
201	4	4	4	4	4	4
202	3	3	4	2	4	4
203	4	4	4	4	4	4
204	3	3	3	4	4	2
205	0	0	0	0	0	0
206	4	4	4	4	4	4
207	3	3	3	3	3	3
208	4	4	4	4	4	4
209	4	4	4	4	4	4
210	3	4	2	4	4	3
211	4	4	4	4	4	4
212	3	3	4	3	4	4
213	4	4	4	4	4	4
214	4	4	4	3	4	4
215	4	4	3	4	4	3
216	4	3	3	4	4	4
217	4	2	0	4	2	4
218	4	3	2	2	3	4
219	4	4	4	4	4	4