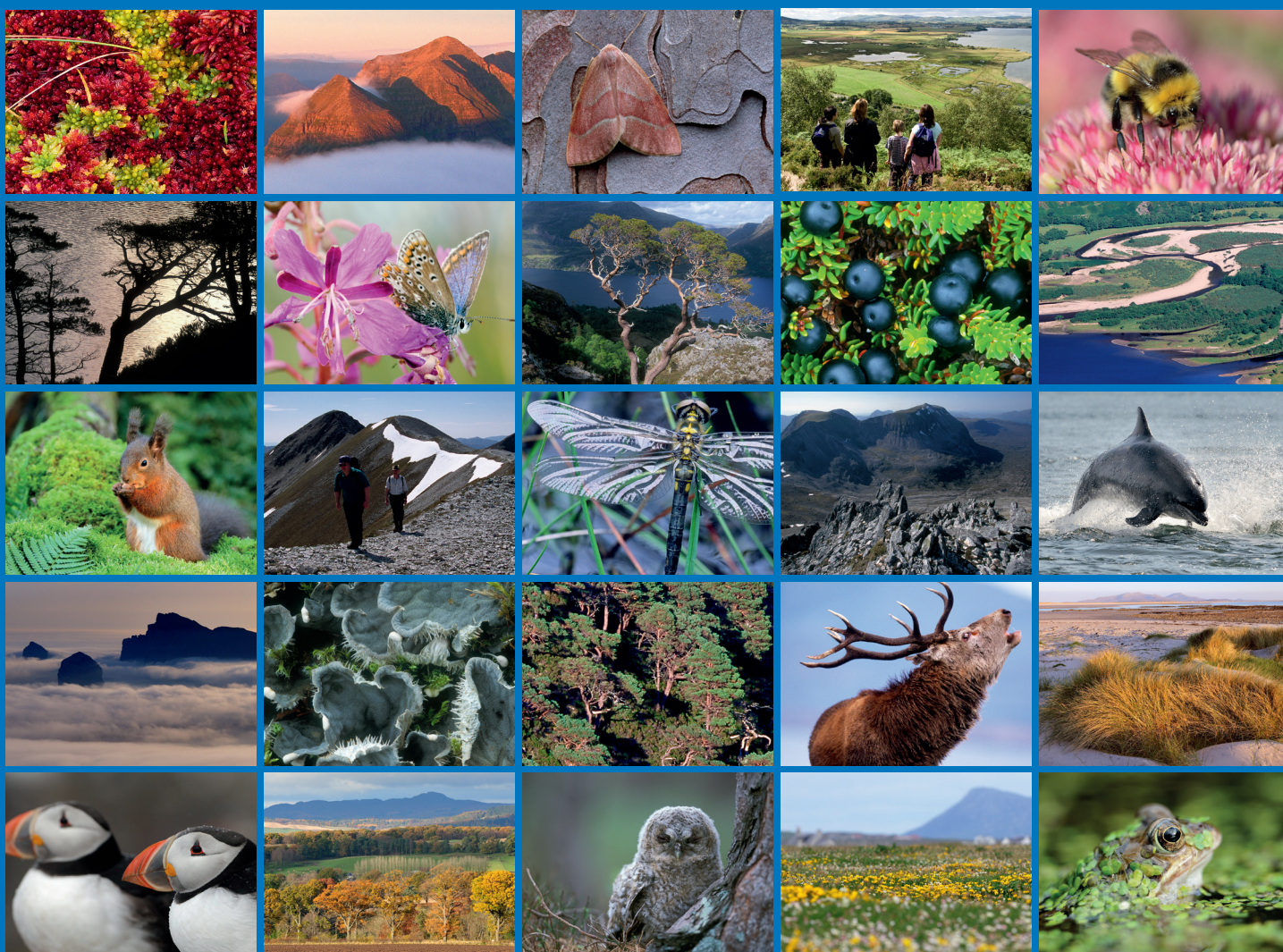


# Linkages between riparian invasive plants, invertebrates and salmonid fish in Scottish rivers



# RESEARCH REPORT

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Research Report No. 1078

## **Linkages between riparian invasive plants, invertebrates and salmonid fish in Scottish rivers**

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# RESEARCH REPORT

# Summary

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## Linkages between riparian invasive plants, invertebrates and salmonid fish in Scottish rivers

**Research Report No. 1078**

**Project No: 015490**

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### **Keywords**

Japanese knotweed; *Fallopia japonica*; Himalayan balsam; *Impatiens glandulifera*; macroinvertebrates; riparian; rivers; salmonid

### **Background**

Invasions by non-native species are reported as one of the greatest threats to global biodiversity, and the invasion of riparian ecosystems by invasive non-native plants (INNP) presents a common and difficult challenge for river and fishery managers. Whilst the various impacts of INNP are well-documented in a range of global studies, the type and extent of ecological changes that riparian INNP invasions induce in invertebrate and salmonid fish communities remains poorly understood. To address these gaps in the literature, this thesis assesses: (1) how riparian INNP (Japanese knotweed (*Fallopia japonica*) and Himalayan balsam (*Impatiens glandulifera*)) alter the abundance, diversity and composition of freshwater macroinvertebrate communities, in relation to environmental variables; (2) how the structure of riparian terrestrial invertebrate communities differs at heavily invaded sites, and whether there is evidence of a difference in INNP species effect and (3) how juvenile salmonids utilise the altered aquatic and terrestrial prey resources at sites with greater INNP cover, and the relative importance of INNP to prey selection in relation to population dynamics and environmental stressors.

Recent field survey data was used to quantify changes in the freshwater and terrestrial invertebrate communities of 24 low order streams in central Scotland. Analyses indicated that whilst greater INNP cover reduced local freshwater macroinvertebrate diversity, their effects were generally subordinate to that of physicochemical variables. However there was evidence of a legacy effect of invasion that presents a constant pressure on freshwater macroinvertebrate communities. Similarly, greater INNP cover reduced terrestrial morphospecies diversity, but also reduced abundance and increased spatial heterogeneity through loss of species at the site scale. INNP cover was found to be the strongest predictor across all assessments of terrestrial invertebrate communities. Juvenile salmonids were observed to change their predatory selection of two taxonomic orders at more heavily invaded sites, but broadly changed their feeding patterns in response to community and environmental stressors, indicating a lesser effect of riparian INNP invasions on salmonid communities.

## Main findings

- INNP (*F. japonica* and *I. glandulifera* throughout the study) constrain and homogenise aquatic invertebrate communities, evidenced by reductions in alpha diversity, Whalley Hawkes Paisley Trigg score and spatial dissimilarity.
- INNP negatively affect terrestrial invertebrate communities, reducing alpha diversity and abundance, and increasing spatial dissimilarity.
- The dietary selections of juvenile salmonid fish appear to be largely unaffected by INNP, suggesting that they are able to adapt to changes in invertebrate community structure and diversity at more heavily invaded sites.
- Whilst actively managing riparian INNP invasions may benefit both aquatic and terrestrial invertebrate communities, there may be minimal impacts on juvenile salmonids.

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# 1. RESPONSES OF AQUATIC INVERTEBRATES TO RIPARIAN INVASIVE NON-NATIVE PLANTS

## 1.1 Study aims

The aim of this study was to assess whether riparian invasive non-native plants (INNP) affect the structure and turnover of aquatic macroinvertebrate communities. Field surveys were used to isolate the magnitude and direction (i.e. positive or negative) of any effect from those of other environmental variables driving aquatic macroinvertebrate community structure. It was hypothesised that changes to riparian vegetation caused by INNP would affect the composition of aquatic invertebrate communities through changes to allochthonous inputs and by modifying local environmental conditions. Aquatic invertebrate communities at sites with higher INNP cover were predicted to exhibit reduced diversity as a result of these physical and chemical changes.

**Question:** How do riparian INNP alter the abundance, diversity and composition of freshwater macroinvertebrate communities?

**Hypothesis:** Higher riparian INNP cover will homogenise the composition of aquatic invertebrate communities through changes to allochthonous inputs and local instream habitat. Aquatic invertebrate communities at sites with higher INNP cover will exhibit reduced diversity as a result of these physical and chemical changes.

## 1.2 Methods

Full details of the methodology can be found in the PhD thesis (Seeney, 2018). Twenty-four study sites were located on six low (1st to 4th) order streams (Strahler, 1957) in catchments across central and southern Scotland (Annex 1). On each stream, a pair of control (uninvaded) sites were located upstream from a pair of invaded sites containing established stands of either Japanese knotweed (*Fallopia japonica*) or Himalayan balsam (*Impatiens glandulifera*). Sites were limited by the size of INNP stands present, and as such were standardised to a 20m length of channel (Annex 2; Figures 2 and 3). Invaded sites were chosen according to the criteria that INNP coverage should exceed 50% of the vegetation cover on at least one bank, their characteristics otherwise being similar to those of upstream uninvaded sites (Sax et al., 2005). These sites were used for all work carried out during this study (and as such, this information is applicable to sections 2.2 and 3.2 of this report). Both *I. glandulifera* and *F. japonica* were assessed collectively (i.e. assessed together as total INNP cover); the focus of the study being on overall effects of invasion-related disturbances rather than differences between similar INNP species.

Benthic invertebrates were sampled using quantitative Surber samples (eight randomly distributed samples per site). Sites were sampled during spring and autumn 2015 to allow seasonal changes in invertebrate composition to be assessed before and after the summer peak of INNP growth. Samples were preserved in the field with 70% industrial methylated spirits and subsequently sorted and identified to the lowest practicable taxonomic level (normally species). Environmental data (including conductivity and pH) were collected at each site, and land use at both the 5m and 50m scale was categorised based on visual assessment and supplemented by aerial photography accessed via Google Earth. The proportion of the channel that was shaded was estimated visually, and the total number of trees in the study reach exceeding 5m in height was recorded as a proxy for the amount of channel shading caused specifically by riparian trees. Sites were surveyed using an electronic distance measuring instrument to map the thalweg profile at each site and to derive an accurate measure of channel slope (Jones, 2010). Wolman pebble counts were taken at each site to characterise substrate heterogeneity (Wolman, 1954), and water velocity and depth were recorded for each Surber sample as a measure of hydraulic habitat

heterogeneity. Vegetation surveys carried out during August 2016 were used to assess total INNP coverage.

Macroinvertebrate community richness was expressed using the sample level alpha diversity (Simpson's macroinvertebrate diversity), and the Whalley Hawkes Paisley Trigg (WHPT) index (Paisley et al., 2014), was used to assess water quality. The proportion of sediment-sensitive invertebrates (PSI) (Extence et al., 2013) was calculated at each of the study sites in both spring and autumn, to assess whether taxa present at invaded sites indicated a greater degree of sediment loading. Additionally, the Bray-Curtis dissimilarity index (Bray and Curtis, 1957) was used to express spatial heterogeneity in stream macroinvertebrate communities. The total number of individuals per sample was also considered as a measure of invertebrate abundance.

### 1.3 Key findings

Riparian INNP cover had the strongest association with Simpson's macroinvertebrate diversity (33% lower at maximum INNP cover) across both seasons, suggesting that high INNP cover in summer has a legacy effect on macroinvertebrate diversity which extends to the following spring (Annex 3). Additionally, INNP cover was positively associated with macroinvertebrate abundance (25% greater at maximum INNP cover) and negatively associated with WHPT score (5% lower at maximum INNP cover), though the latter effect size was relatively minor in comparison to other environmental predictors (conductivity, habitat heterogeneity and substrate diversity). This suggests overall that invaded sites foster a greater abundance, but lower diversity of pollution-tolerant, low-scoring WHPT taxa. The indication that habitat quality for macroinvertebrates is lower at invaded sites is also consistent with the decreased spatial dissimilarity in composition between samples. Indicator species analysis demonstrated that more taxa with lower WHPT scores showed fidelity to invaded sites (including Gammaridae, *Dicranota* spp. and Elmidae taxa), whilst more taxa with higher WHPT scores showed fidelity to uninvaded sites (including *Rhyacophila* spp., *Lepidostoma hirtum*, *Protonemura meyeri* and *Amphinemura sulcicollis*).

Macroinvertebrate composition was most heterogeneous at sites with little or no invasive cover. PSI analysis suggested that the benthic habitat at most sites in this study was minimally or only slightly sedimented, offering no evidence to link invertebrate community responses to INNP cover through channel sedimentation.



## 2. RESPONSES OF TERRESTRIAL INVERTEBRATES TO INVASION OF RIPARIAN HABITATS BY NON-NATIVE PLANTS

### 2.1 Study aims

The aim of this study was to compare the effects of *F. japonica* and *I. glandulifera* on terrestrial invertebrate community composition, evaluating the relative effects of these two INNP species against other environmental factors, such as soil organic content and native plant community structure.

**Question:** How does the structure of riparian terrestrial invertebrate communities differ at sites invaded by INNP, and is there evidence of a difference in effect between *Fallopia japonica* and *Impatiens glandulifera*?

**Hypothesis:** High levels of INNP cover will reduce the diversity of above-ground terrestrial invertebrate communities through changes to local microhabitat conditions. Whilst *F. japonica* and *I. glandulifera* exert similar dominant effects on riparian vegetation communities, the biological differences between these two species are expected to cause differing effects on the assessed invertebrate community indices.

### 2.2 Methods

Full details of the methodology can be found in the PhD thesis (Seeney, 2018). Terrestrial invertebrates were sampled using pitfall traps installed along a linear transect containing 12 traps. Invertebrates were identified to morphospecies (Báldi, 2003, Krell, 2004). Sites (Annex 2; Figures 2 and 3) were sampled for one week periods during June and August 2016 to allow changes in invertebrate composition to be assessed in response to the summer peak of INNP growth. Land use at each site was categorised at both the 5m and 50m scale based on a visual assessment and aerial photographs accessed via Google Earth, to give an estimate of the proportion of natural and artificial land use (as defined in the River Habitat Survey (Raven et al., 1998)). Site orientation (recorded as degrees from north) and site elevation were also obtained from Google Earth, and the total number of trees in the study reach exceeding 5m in height was recorded in the field as a proxy for the amount of channel shading caused specifically by riparian tree cover. Five soil cores (6cm depth, 4cm diameter) were taken at each site, spread equidistantly along the pitfall trap transect. Loss on ignition (LOI) was used to measure soil organic content (Heiri et al., 2001).

Terrestrial invertebrate community morphospecies diversity was expressed using both the sample level alpha and site level gamma diversity, based on the full complement of morphospecies in each pitfall trap and at each site respectively. Total invertebrate abundance per pitfall trap was also calculated for each weekly sampling period. The Bray-Curtis dissimilarity index was used to express spatial dissimilarity in terrestrial invertebrate communities, giving a measure of turnover between individual pitfall traps at a given site, based on morphospecies composition. Given that the distance between pitfall traps affects the capture rates of ground-dwelling arthropods (Zhao et al., 2013), pairwise Bray-Curtis dissimilarities were weighted based on distances between pairs of traps.

Native plant community richness was expressed using Shannon's diversity index. Plant cover estimates obtained from vegetation surveys were adjusted based on the number of quadrats sampled at each site. Additionally, Ellenberg's indicator scores (Ellenberg, 1986) were used to express the ecological attributes of the native plant community.

### 2.3 Key findings

Overall, INNP were associated with reduced terrestrial invertebrate morphospecies abundance (57% lower at maximum INNP cover) and both alpha (sample level) and gamma

(site level) diversity (39% and 21% lower at maximum INNP cover). More morphospecies were indicative of sites invaded by *I. glandulifera* than *F. japonica*, suggesting that environmental conditions at *F. japonica* sites are more prohibitive to invertebrates. The morphospecies most indicative of uninvaded sites included Collembola and taxa from the Phoridae and Staphylinidae families of Coleoptera. Since the latter two favour decaying organic matter, this supports the theory that increased litter diversity fosters invertebrate diversity (Scherber et al., 2010, Lecerf et al., 2011). Acari were most strongly indicative of sites invaded by either *F. japonica* or *I. glandulifera*, which is unsurprising given their generalist tendencies and reputation for colonising most aquatic and terrestrial habitats by exploiting a wide range of resources (Vacante, 2016).

The association of INNP with increased spatial dissimilarity in assemblages is therefore unlikely to be beneficial, as the increased heterogeneity between traps arises from losing morphospecies, rather than gaining them. INNP species had the greatest effect on terrestrial invertebrate communities, regardless of local environmental conditions, demonstrating their ability to influence ecosystems and cause impacts extending beyond the immediate plant community. It is evident that INNP have measurable and significant impacts on these communities, which may ultimately affect energy transfer and other linkages between terrestrial and aquatic systems across a range of trophic levels.

### 3. THE IMPACT OF INVASIVE RIPARIAN PLANTS ON THE DIETARY SELECTIONS OF JUVENILE SALMONID FISH

#### 3.1 Study aims

Although the importance of the riparian zone to salmonid fish is well documented (McCormick and Harrison, 2011, Ryan and Kelly-Quinn, 2015), less is known about specific links between riparian INNP and the population dynamics and feeding preferences of salmonids. It is also becoming increasingly recognised that it is not sufficient to simply assess the immediately obvious effects of invasion. More obscure (but potentially critical) interactions must be assessed, such as changes in trophic networks and consequent impacts on ecosystem functioning (Simberloff et al., 2013), range expansions due to climate change coupled with riparian invasion (Lawrence et al., 2014), and linkages between invasion success and environmental conditions (Thomsen et al., 2014). More broadly, there is a present need for more cooperative studies, incorporating relevant research and management plans where common species, environments and organisations are involved (Macchi and Vigliano, 2014).

**Question:** How do INNP affect the dietary selections of juvenile salmonid fish in relation to population dynamics and environmental stressors?

**Hypothesis:** Changes to terrestrial and aquatic invertebrate communities at sites with higher INNP cover will be reflected in alterations to the dietary selections made by juvenile salmonid fish.

#### 3.2 Methods

Full details of the methodology can be found in the PhD thesis (Seeney, 2018). Sites were generally selected based on suitability and accessibility for both juvenile and adult salmonid fish (Annex 2; Figures 2 and 3), and were chosen in consultation with local fisheries trusts to ensure that a healthy and representative population of juvenile salmonid fish would be present at each location.

Quantitative electrofishing surveys were carried out in August 2015 and 2016, targeting *S. trutta* and *S. salar*. Sampling continued until three runs had been completed, at which point all captured *S. trutta* and *S. salar* were anaesthetised using tricaine mesylate (MS-222) to minimise stress whilst fork length (to the nearest mm) and body mass (to the nearest 0.1g) were recorded. In order to estimate the relative abundance of age classes at each site, fork length data was imported into the FAO-ILARM Fish Stock Assessment Tool (FiSAT), and a modal progression analysis was run using Bhattacharya's method (Bolland et al., 2007). Additionally, the fork length for each fish was used to estimate cohorts of fish based upon the range and frequency of fork lengths across all sites on a particular river. Based on this preliminary cohort assessment, only 0+ and 1+ fish were taken forward for dietary analysis, as these comprised 94% of fish analysed over the two year sampling period.

The gastric lavage procedure was chosen to assess the dietary choices of juvenile salmonids (Strange and Kennedy, 1981). The gut contents of a number of captured fish (up to a maximum of 10 per species age-class) were removed for analysis. The stomach flushing procedure was not carried out on individuals with fork length below 60mm, as this was restricted by the project licence (PPL 70/8673).

In order to assess the feeding strategies employed by salmonids at study sites, an electivity index was used. A common measure to quantify prey selection is Ivlev's electivity index (Ivlev, 1961), but the values generated by this index depend on a number of varying factors, such as the relative abundances of different food types in the environment. Furthermore, modelling a variety of selectivity or avoidance responses based on the proportional selection

of a large number of different invertebrate taxa posed a problem when considering the best model design to analyse the data. For these reasons, the Manly-Chesson index (Manly, 1974, Chesson, 1978, Chesson, 1983) was chosen as the best and most appropriate representation of salmonid dietary preferences for this study. For this study, prey items were categorised into broad taxa groupings (Ephemeroptera, Plecoptera, Trichoptera, Simuliidae, Chironomidae, Gammaridae, other aquatic invertebrate taxa, and aerial invertebrate taxa), in order to be able to compare dietary choices and prey availability from both 2015 and 2016 samples.

### 3.3 Key findings

INNP species were only observed to have significant effects on the dietary selection by juvenile salmonids of two out of eight main taxa groups (increased selection of Ephemeroptera, reduced selection of Chironomidae, and no detectable effects on Plecoptera, Trichoptera, Simuliidae, Gammaridae, other aquatic invertebrate taxa, and aerial invertebrate taxa). This suggests that whilst INNP may affect the dietary choices of juvenile salmonids, these changes in diet appear to be relatively limited and do not apply to the full range of available prey resources. Furthermore, this effect was only observed for *I. glandulifera* and not for *F. japonica*, indicating that the two INNP species examined in this study are likely exerting their effects through different pathways.

The findings of previous chapters have demonstrated that INNP have measureable effects on riparian communities of both aquatic and terrestrial invertebrates. Whilst this suggests that sites with the greatest riparian INNP cover are ecologically poorer in terms of their invertebrate communities compared to their uninvaded counterparts, this diet study suggests that for the most part, juvenile salmonid diet selection is not affected to the same degree. Furthermore, INNP appear to even increase the rate at which both *S. trutta* and *S. salar* are able to consume Ephemeroptera, one of their preferred and commonly selected prey items. It may be that the replacement of a riparian tree canopy by a comparatively smaller INNP riparian overhang increases the overall insolation time of the channel at more heavily invaded sites. This in turn could promote drifting behaviour in Ephemeroptera for a longer period of time, in order to avoid biological damage (Hitchings, 2009), simultaneously making them more available to foraging salmonids.

#### 4. MANAGEMENT IMPLICATIONS FOR INVASIVE NON-NATIVE PLANTS

It is difficult to state with confidence that any management action will yield a defined result, taking into account site-specific properties, interactions between stressors (Vinebrooke et al., 2004, Jackson et al., 2016) species-specific responses (Altermatt et al., 2013) and the external factors that drive stochastic variation in ecosystems. Furthermore, whilst this study demonstrates negative associations between INNP cover and both aquatic and terrestrial invertebrate communities, these effect sizes are reasonably small and as such may offer a low benefit-cost ratio for any management efforts. Many other variables influenced macroinvertebrate communities, notably conductivity, channel slope, number of trees, channel shading, physical habitat heterogeneity and Ellenberg indicators for light and moisture, all of which themselves are prone to human modification. Caution must therefore be exercised when using these findings to inform management policy, as although removing riparian INNP cover at the local scale may deliver some ecological improvements, it may also yield a relatively low benefit-cost ratio to invertebrates and juvenile salmonids if overwhelmed by effects of other anthropogenic stressors at coarser scales (Simberloff et al., 2013, Sundermann et al., 2013, Seeney et al., 2018). Legacy effects of non-native invasions may also delay expected ecological responses (Cuddington, 2012, Corbin and D'Antonio, 2017), and certain treatment or removal approaches may themselves adversely affect native biota (Flory and Clay, 2009, Kettenring and Adams, 2011).

Whilst this project (Seeney, 2018) does not examine recovery following INNP removal, it does quantify the ecological impact of two prominent, widespread and often managed INNP species on riparian ecosystems. Maximum INNP cover was associated with reductions in the diversity (-33%), WHPT score (-5%) and dissimilarity (-12%) of aquatic macroinvertebrate communities, fostering an increased abundance (+25%) of tolerant taxa. Similarly, maximum INNP cover was associated with reductions in sample (-39%) and site level (-21%, *I. glandulifera* only) diversity and abundance (-57%) of terrestrial invertebrate morphospecies. Although this fostered more spatially heterogeneous assemblages (+26%, *F. japonica*; +18%, *I. glandulifera*), this was as a result of morphospecies extirpation.

These findings offer support for the management of riparian INNP species, as heavily invaded riparian sites are clearly of a lower ecological quality than their uninvaded counterparts. Although the immediate responses and ecological gains made by small scale INNP management may be relatively small, preventing the spread of invasive species via early intervention is important (Simberloff et al., 2013) and is likely to be cheaper than future treatment efforts once the invasion has spread (Mack et al., 2000). However, given the relatively low number of taxa groups that are predated upon in significantly different proportions by juvenile salmonids at invaded sites, it is unlikely that these improvements will be felt by resident *S. salar* and *S. trutta* populations at invaded sites. It is possible that ecological improvements may be seen instead through in-stream and bankside morphological improvements following INNP removal and the re-establishment of native vegetation. However, these pathways were not extensively tested within this PhD project (Seeney, 2018), and this area is therefore highlighted for consideration in future studies.

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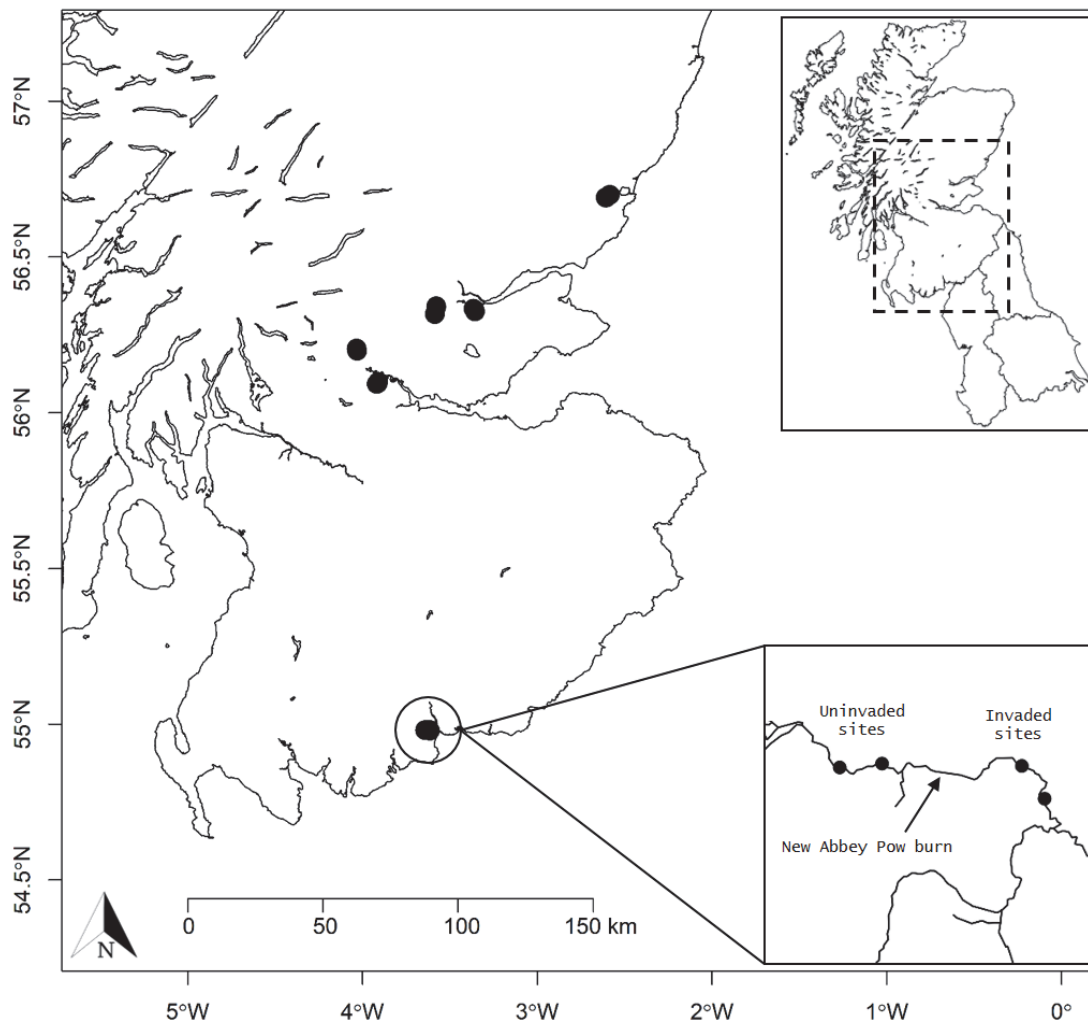
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## ANNEX 1: MAP OF STUDY SITES



*Figure 1. Map of study sites with example for the New Abbey Pow (Nith catchment) inset. Larger inset indicates general location of all study sites across central Scotland.*

## ANNEX 2: EXAMPLES OF STUDY SITES WITH INVASIVE NON-NATIVE PLANTS



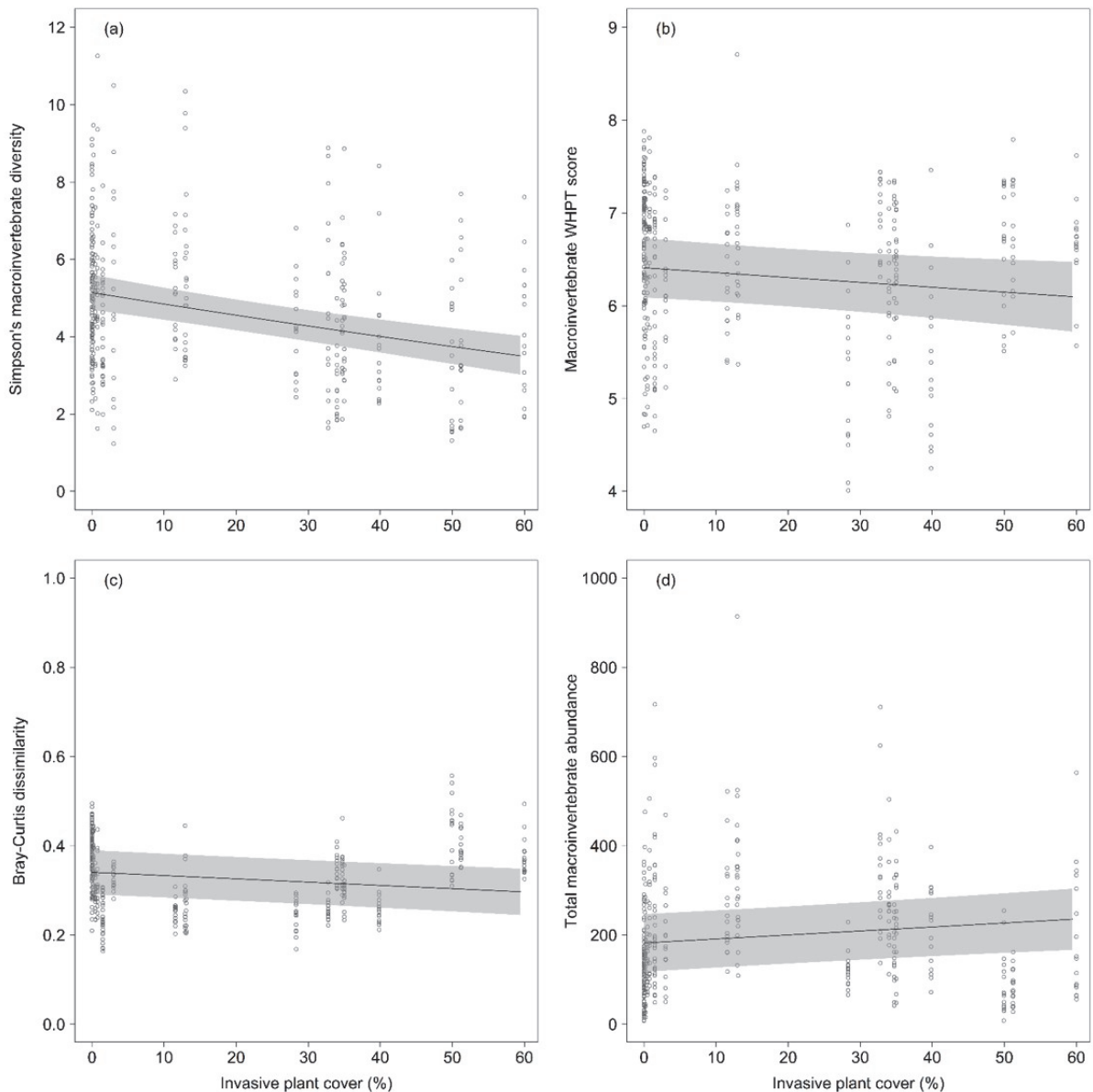
Figure 2. A study site on the Pow burn (South Esk catchment), invaded by *Impatiens glandulifera*.



Figure 3. A study site on the Argaty burn (Forth catchment), invaded by *Fallopia japonica*.



### ANNEX 3: RESPONSES OF AQUATIC AND TERRESTRIAL INVERTEBRATES TO INVASIVE NON-NATIVE PLANTS



*Figure 4. Responses of aquatic macroinvertebrates to invasive non-native plants. Full model predicted values (shaded polygon shows  $\pm 95\%$  confidence intervals) from the LMM analyses of (a) Simpson's macroinvertebrate diversity, (b) macroinvertebrate WHPT score, (c) spatial dissimilarity for individual Surber samples and (d) macroinvertebrate abundance for individual Surber samples, all plotted against invasive plant cover.*

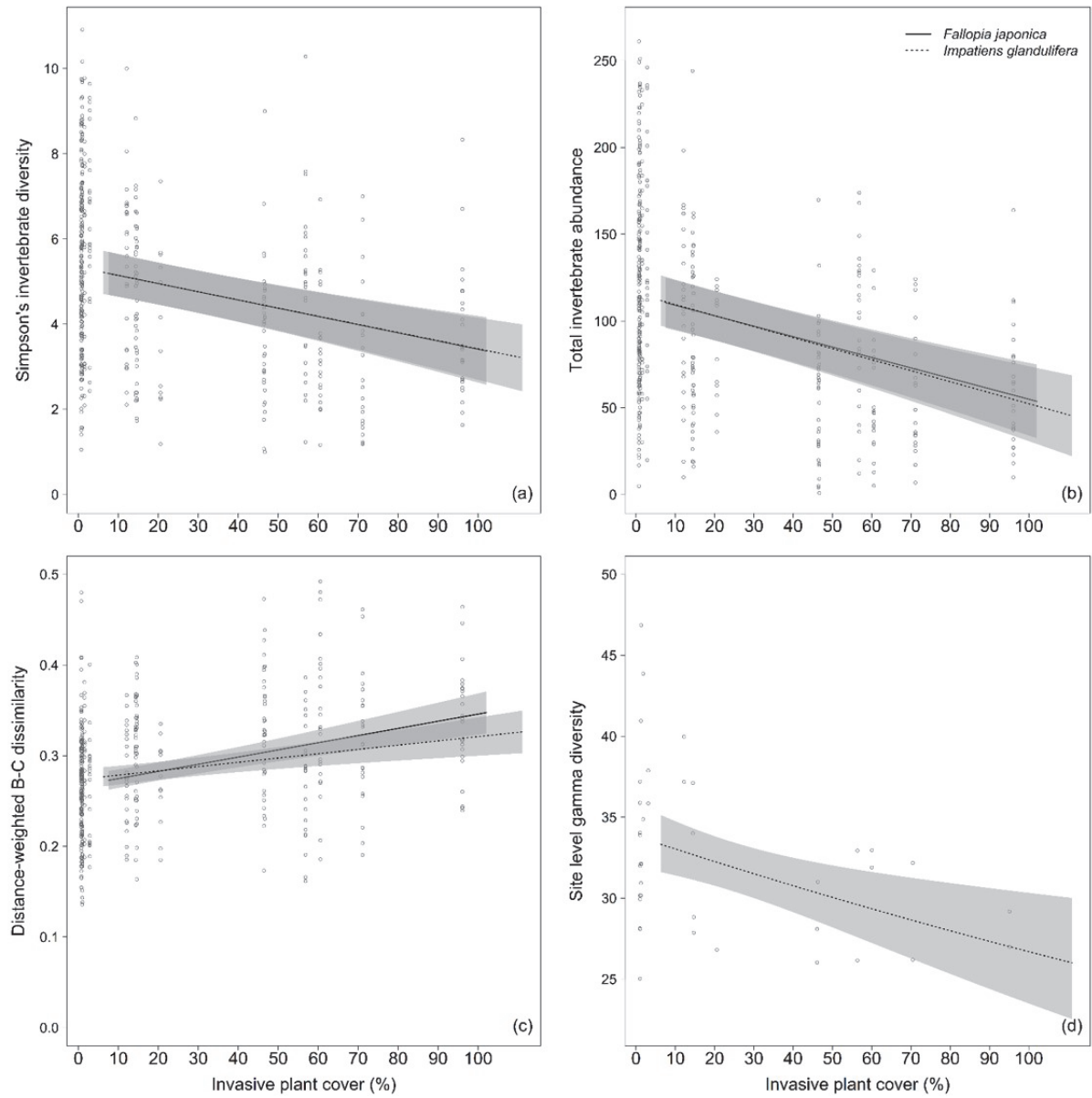


Figure 5. Responses of terrestrial invertebrates to invasive non-native plants. Full model predicted values (shaded polygon shows  $\pm 95\%$  confidence intervals) from the LMM analyses of (a) Simpson's macroinvertebrate diversity, (b) total macroinvertebrate abundance, (c) spatial dissimilarity for individual pitfall traps and (d) macroinvertebrate gamma diversity, all plotted against invasive plant cover.

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