CEE review 05-007

WHAT ARE THE EFFECTS OF SALMONID STOCKING IN LAKES ON NATIVE FISH POPULATIONS AND OTHER FAUNA AND FLORA? PART A: EFFECTS ON NATIVE BIOTA

Systematic Review

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Systematic Review Summary

Background

In Europe and North America, lakes are often stocked with salmonid species, primarily to provide game fisheries, but concerns have long been raised about the ecological consequences of this practice. The addition of a species high in the food chain can impact other organisms, some of which may be of conservation value. Interbreeding between stocked and native fish may affect population viability and fish taxa can be potentially lost through hybridization, competition or inadvertently introduced diseases. The impacts of salmonid stocking in rivers are widely reported in contrast to their impacts in lakes. The impact of salmonid stocking on the abundance and species richness of non-stocked native fish species in lakes is a primary focus of the review together with changes in the abundance or species richness of other fauna and flora including amphibians, invertebrates, aquatic plants and plankton.

Objectives

What are the effects of salmonid stocking in lakes on native fish populations?

What are the effects of salmonid stocking in lakes on flora and fauna other than fish?

Search strategy

Electronic databases and web sites were searched using key words. Bibliographies were also searched and personal contacts were made with researchers to retrieve relevant material.

Selection criteria

Studies were included in the review where the following criteria were met:
1. *Subject*: lakes
2. *Intervention*: stocking with brown trout *Salmo trutta*, rainbow trout *Oncorhynchus mykiss*, Atlantic salmon *Salmo salar* (landlocked forms), arctic charr *Salvelinus alpinus*, brook trout *Salvelinus fontinalis* and charr X salmon hybrids, or other salmonids when present in combination with the above.
3. *Outcomes*: primary outcomes were changes in abundance or species richness of non-stocked fish species. Secondary outcomes were changes in abundance or richness of other species, and changes in size of individual fish.
4. *Type of study*: any field (*in situ*) study

Data collection and analysis

Study inclusion assessments were performed and the observed agreement between independent reviewers was “substantial” indicating that the relevance assessment was repeatable. Relevant studies were categorized according to the subject, study type and outcome using an *a priori* data extraction protocol. In the case of amphibians, sufficient data were captured to derive effect sizes which were combined using random effects meta-analysis.

Main results

Despite the apparently large literature base available on this topic, insufficient information is available regarding the impact of salmonid stocking in lakes on non-stocked fish species for management to be based on empirical evidence.

Of 316 studies identified with relevant titles and abstracts, six present sufficient standardized empirical measures for synthesis of data on the effects of salmonid stocking in lakes on flora and fauna other than fish. Available evidence indicates that Urodela (newts and salamanders) are less likely to be found in water bodies stocked with salmonids than water bodies that do not contain salmonids. There is no significant difference in anuran (frog and toad) occupancy between stocked and unstocked water bodies. However, considerable variation in responses remains unexplained for both newts and frogs. *Rana cascadae* (Cascades frog) and *Rana muscosa* (Mountain yellow-legged frog) are both significantly less likely to be present in water bodies stocked with salmonids than water bodies which do not, whilst the converse is true for *Bufo boreas* (Western toad).

Results for other biota, including fish, are not presented in sufficient numbers or in consistent formats across studies, making it impossible to draw robust conclusions regarding any other impact of stocked salmonids on lake ecosystems from the data currently available.

Conclusions

There is very little evidence available on impacts of stocked salmonids on lake ecosystems. Monitoring the impacts of stocking programmes, both before and after stocking events, is necessary in order to develop an evidence base.

Lakes into which salmonids have been introduced are less likely to contain newts or salamanders than those which contain no salmonids. A precautionary approach to stocking with salmonids is necessary if potentially deleterious impacts to anuran populations are to be avoided.

The impact of stocking on frogs and toads is variable, but overall, available evidence suggests that stocked lakes are as likely to contain them as unstocked lakes. In general, they therefore appear less vulnerable to stocking than newts and salamanders.However, *Rana cascadae* (Cascades frog) and *Rana muscosa* (Mountain yellowlegged frog) are both significantly less likely to be present in water bodies stocked with salmonids than water bodies which do not. The latter species is of conservation concern and a precautionary approach to stocking with salmonids is necessary if potentially deleterious impacts to *R. cascadae* and *R. muscosa* populations are to be avoided.

WHAT ARE THE EFFECTS OF SALMONID STOCKING IN LAKES ON NATIVE FISH POPULATIONS AND OTHER FAUNA AND FLORA?
PART A: EFFECTS ON NATIVE BIOTA

1. Background

In Europe, North America and Australasia, lakes are often stocked with salmonids to provide game fisheries. Stocking occurs in fishless lakes, as well as those with historical populations of salmonids or other fishes. These fisheries have a high socioeconomic value, but there is concern regarding the ecological impact of stocking a species high in the food chain, especially on other organisms of conservation value (Aprahamian *et al.* 2003; Saura *et al.* 1990; Brett & Goldman 1996). Although salmonids are generally considered to be "low risk" in this context (Noakes *et al.* 2000), the conditions under which they are often stocked, at high densities unrelated to environmental conditions and carrying capacity (as is the case in put-and-take fisheries) are quite removed from natural conditions, and warrant further investigation.

The impact of stocking on the abundance and species richness of non-stocked native fish species is the primary focus of this review, although impacts on other fauna and flora are also considered. Lakes and ponds may provide an important rearing habitat for salmonids, as well as providing migration corridors for anadromous salmonids (Bonar *et al.* 2004). As wild fish populations continue to decline, fisheries managers are increasingly concerned about how hatchery and stocking operations might be contributing to declines of highly valued wild populations (Pearsons & Hopley 1999), although there is discussion as to whether the stocked salmonids displace native fish, or replace them following unrelated decline (Dunham *et al.* 2002). Interbreeding between stocked and native fish is also of major concern as population viability may be affected (Youngson *et al.* 2003), and native species may be lost through hybridization or be out-competed. Hatchery stocks may also act as vectors of salmonid diseases, and introduce parasites to previously unaffected populations. Not only can this lead to mortality of wild fish stocks, but can be financially undesirable to fisheries managers and practitioners.

Secondary concerns include changes in the abundance or species richness of other fauna and flora. It is believed that salmonid introductions may impact on the amphibians, invertebrates, aquatic plants and plankton of ecosystems to which they are introduced. The impact of salmonid introductions to fishless lakes is believed to have a considerable effect on native biota (Knapp 1996). Some impacted species, particularly amphibians, may be of special conservation concern, and are regarded as indicators of environmental health (Bury *et al.* 1995, Collins & Storfer 2003). Other common lake taxa, such as *Daphnia*, act as keystones, highlighting changes in the ecosystem resulting from the stocking of salmonids (Stockner & Porter 1988).

The impact of salmonid stocking may be modified by variation in the number of fish stocked and the time of year when stocking occurs, which accordingly impacts carrying capacity (Milner *et al.* 2003). Other potential variables identified by one stakeholder organisation, the Countryside Council for Wales (CCW), in order of importance are: lake type (mean depth and area determine habitat availability and limit carrying capacity, Milner *et al.* 2003), sampling method used to assess fish abundance (e.g. rod survey, netting, electro-fishing), presence/absence of sensitive features, initial stocking density (as salmonids are density dependent, Gibson 1993, Elliott 1994), species stocked (which impacts carrying capacity Milner *et al.* 2003), size/age class when stocked (which again impacts carrying capacity Milner *et al.* 2003), follow-up period (duration of monitoring) and the occurrence of any acid episodes (as salmonids do not respond well to variation in pH, Hendry *et al.* 2003). The impact of these potential effect modifiers also requires investigation.

2. Objectives

2.1 Primary objective

To systematically collate and synthesise published and unpublished evidence in order to address the following questions:

1. "What are the effects of salmonid stocking in lakes on native fish populations?"
2. "What are the effects of salmonid stocking in lakes on flora and fauna other than fish?"

2.2 Secondary objective

What influence does the number of fish stocked, time of year when stocking occurs, lake type (mean depth and area), sampling method used to assess fish abundance (e.g. rod survey, netting, electro-fishing), presence/absence of sensitive features, initial stocking density, species stocked, size/age class when stocked, follow-up period (i.e.duration of monitoring) and the occurrence of any acid episodes have on the impact of salmonid stocking in lakes?

3. Methods

3.1 Question formulation

The Countryside Council for Wales (CCW) identified the need for a systematic review to evaluate the potential ecosystem effects of salmonid stocking in lakes on native fish populations and other fauna and flora.

The specific question to be addressed was formulated through discussion between the CEBC and UK-based stakeholder organisations (i.e. those with an interest in the results of the review). In total 12 stakeholder organisations were contacted and invited to comment on a draft of the proposed methodological protocol: Association of Fisheries Trusts; Countryside Council for Wales (CCW); Centre for Environment, Fisheries and Aquaculture Science (CEFAS); The Environment Agency (EA); English Nature (EN); Fisheries and Angling Conservation Trust Ltd. (FACT), Fisheries Research Service (Scotland) (FRS); National Trust (NT); Royal Society for the Protection of Birds (RSPB); and Scottish Environmental Protection Agency (SEPA).

The question comprised three key elements (Table 1):

1. *Subject*: (*i.e. the unit of study to which the intervention is to be applied*): lakes
2. *Intervention*: stocking with brown trout, rainbow trout, Atlantic salmon (landlocked forms), arctic charr, brook charr, and charr X salmon hybrids.

3. *Outcome*: primary outcomes were changes in abundance or species richness of non-stocked fish species. Secondary outcomes were changes in abundance or richness of other species, and changes in size of individual fish.

Table 1: Definition of the components of the systematic review question.

Subject	**Intervention**	**Outcome**	
Temperate lake systems	Stocking with: • Brown trout *Salmo trutta* • Rainbow trout *Oncorhynchus mykiss* • Atlantic salmon *Salmo salar* (landlocked forms) • Arctic charr *Salvelinus alpinus* • Brook charr *Salvelinus fontinalis* • *Salvelinus* X *Salmo* hybrids vs. no stocking	**Primary**	Change in abundance or species richness of non-stocked fish species and lampreys
		Secondary	Changes in the abundance or species richness of other species including amphibians, invertebrates, aquatic plants and plankton. Change in size of individual fish
		Tertiary	Any other outcomes

3.2 Search strategy

3.2.1 General methodology

Relevant studies were identified through computerised searches of the following electronic databases; Agricola, Copac, Digital Dissertations Online, Directory of Open Access Journals, English Nature's "Wildlink", Europa, Index to Theses Online, ISI Web of Knowledge (inc. ISI Web of Science and ISI Proceedings), JSTOR, Science Direct and Scopus.

The search terms used as identified in the protocol were:
1. Trout*
2. *Salmo**
3. *Oncorhynchus* AND *mykiss*
4. Charr
5. *Salvelinus*
6. Amphibian* AND fish*

Additional database searching was undertaken using the following terms in combination with the above:
7. (stock OR stocking OR stocked)
8. stock*
9. introduce*
10. invertebrate*
11. (macrophyt* OR "aquatic plant*")
12. plankton

3.2.2 Specialist sources

Publication searches were undertaken on conservation and statutory organization websites (using the search terms: salmon trout stocking lakes – in order to reduce search time of a vast salmonid literature): Countryside Council for Wales (CCW); Department of Agriculture and Rural Development (DARD); Department of Environment, Food and Rural Affairs (DEFRA); English Nature (EN); Environment Agency (EA); FRS Freshwater Laboratory (formerly Freshwater Fisheries Laboratory); Joint Nature Conservancy Council (JNCC); National Parks and Wildlife Service (NPWS); Fisheries and Wildlife Service and Scottish Natural Heritage (SNH).

Additional web searching was conducted on topics that had yielded considerable data during the database searching stage. Topics which appeared unlikely to yield sufficient data to enable a meta-analysis were not searched beyond the database stage. Search engines and web resources used were FishBase.org, graylit.osi.gov, conservationevidence.com, Google, Google Scholar, Scirus, Biology Browser and Dogpile. Foreign language searches were not conducted for this review. However, the search identified studies on a global scale (i.e. studies from North America, Europe outside the UK and Australasia) all of which were included in the systematic review process, irrespective of geographical location.

3.3 Study inclusion criteria

Articles from the initial database searches (using terms 1-6) were initially filtered by title and any obviously irrelevant articles were removed. Subsequently, the abstracts of the remainder were examined with regard to possible relevance. All of these articles (n = 415) were assessed for relevance by a second independent reviewer; agreement on inclusion between the reviewers was deemed to be "substantial" (Cohen's Kappa test: K = 0.6). The results from the second phase of database searching (using terms 7- 12) were filtered at title and abstract level simultaneously, due to the smaller sample size. Articles were accepted for viewing at full text if it appeared that they might contain information pertinent to the review question, or if the abstract was ambiguous or missing, and did not allow inferences to be drawn about the article content.

Articles viewed at full text were admitted to different categories based on the outcomes and subjects considered (herpetofauna, macrophytes, plankton, invertebrates, fish or genetics. However studies concerning the genetic impacts were not included in this review and will be dealt with elsewhere. Studies obtained at full text were then assessed against the subject, intervention and outcomes listed in 3.1 above, as it was often unclear from the abstract whether the stocked fishes were salmonids or if the water bodies were lakes. Many articles had missing or incomplete abstracts and were deemed not relevant upon further inspection. Retrieval of full text information was halted when it became clear that insufficient evidence existed for synthesis (macrophytes and invertebrates).

3.4 Data extraction

Insufficient data was available for extraction and synthesis for any taxon other than herptofauna. Summaries of the available information are presented in Appendix 1. The small subset of herptofauna articles presenting data were assessed for eligibility and suitability for meta-analysis based on the existence of dichotomous outcome data (see below) by a single reviewer with reference to a second reviewer in cases of uncertainty.

Data from eligible trials were abstracted into an excel database. Data were extracted where possible for presence and absence of salmonids and amphibians in lakes (lake occupancy). Six studies (Knapp *et al.* 2001, Lecis & Norris 2003, Orizaola & Braña 2006, Pilliod & Peterson 2000, Tyler *et al.* 1998 and Welsh *et al.* 2006) yielded 19 data points. Data extraction is summarised in Appendix 2.

3.5 Data synthesis

Data synthesis was only possible for a small subset of studies concerning herptofauna. Risk ratios (defining the absence of amphibians as the event) and pooled treatment effects across studies were generated, calculating a weighted average risk ratio for urodeles (salamanders and newts) and anurans (frogs and toads) in a random effects model (DerSimonian & Laird 1986) with the estimate of heterogeneity being taken from the Mantel-Haenszel model. Risk ratios compare the risk of having an event (absence of amphibians) between two groups (water bodies which contain introduced salmonids and water bodies without salmonids). Therefore our risk ratio analysis determines whether amphibians are more likely to be absent from lakes containing salmonids than those without. If an intervention (in this case salmonid stocking) has an identical effect (in this case, the effect is absence of amphibians) to the control (no salmonids), the risk ratio will be 1. If the chance of an effect is reduced by the intervention, the risk ratio will be less than 1; if it increases the chance of having the event, the risk ratio will be bigger than 1. Therefore, a risk ratio of greater than one means that amphibians are less likely to be present in water bodies stocked with salmonids than salmonid free water bodies.

The presence of publication bias in the entire amphibian dataset was investigated by means of a funnel plot (Sterne 2001). We tested for heterogeneity using chi-squared. We carried out sensitivity analyses using odds ratios to investigate whether choice of summary statistic is critical to the conclusions of the meta-analysis. The results of the meta-analysis were also re-expressed using risk difference as an absolute effect measure. Statistical analyses were performed using Stata 8.2 (StataCorp, College Station, Texas).

4. Results

4.1 Review statistics

Searching was completed in October 2006. Literature searching began before the finalisation of the protocol, and due to the broad terms used, especially in relation to salmonid species, large numbers of references were obtained. Much general information regarding the review question was present on organisational websites, but this literature did not yield any specific empirical data regarding salmonid impact. Of 316 articles identified with relevant titles and abstracts, only six presented sufficient standardised empirical measures for synthesis (Figure 1).

4.2 Study quality

Insufficient data points exist for sensitivity analyses to investigate the impact of variation in study quality, therefore study characteristics were summarized qualitatively (Table 2).

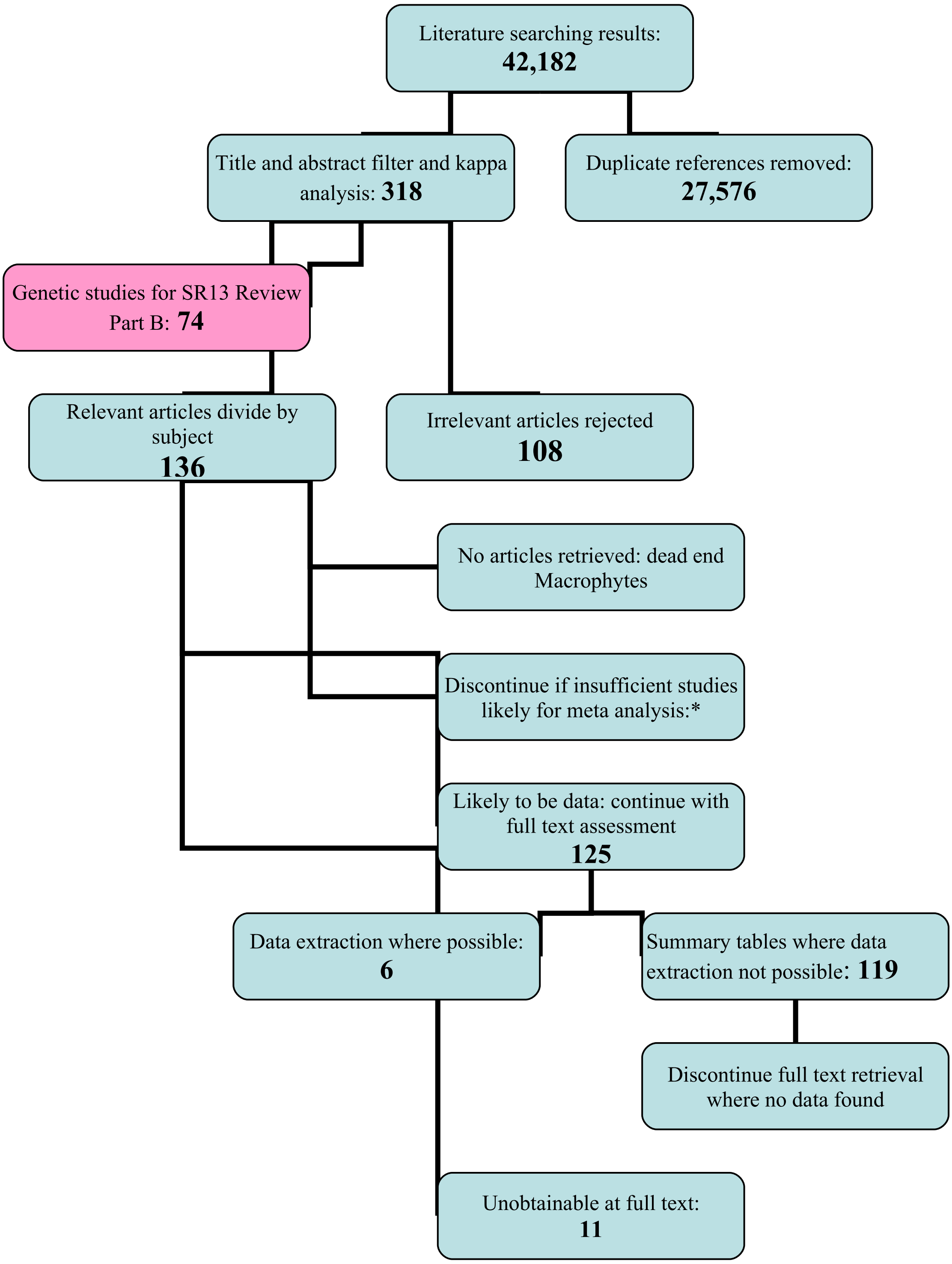

Fig.1: Numbers of articles at each stage of the process mapped onto the decision tree

Table 2: Characteristics of studies included in amphibian analyses.

Reference *	Number of sites			Sampling methodology	
	Total	Treatment (fish)	Control (no fish)	Fish survey technique	Amphibian survey technique
Knapp *et al.* 2001 (1)	504	289	215	Visual and gill net surveys	Visual encounter surveys of entire shoreline
Lecis & Norris 2003 (1)	22	3	19	Field sampling of sites using visual surveys – at least 1km length	Field sampling of sites using visual surveys – at least 1km length
Orizaola & Braña 2006 (10)	30	8	22	Visual surveys, communication with local fisheries authorities and previous surveys	Visual surveys and dip netting the entire shoreline
Pilliod & Peterson 2000 (1)	73	41	32	Sub-sampling at watershed scale, technique unknown	Sub-sampling at watershed scale, technique unknown
Tyler *et al.* 1998 (1)	17	9	8	Stocking records, field observations and recorded data	Snorkel surveys on 4*25m sections of each lake shore
Welsh *et al.* 2006 (5)	218	191	27	Visual surveying and gill nets	Shoreline visual encounter surveys

* The number in brackets following the reference denotes the number of independent data points extracted from that study.

4.3 Amphibian analysis

The risk ratios of the amphibians and the uncertainty surrounding them are variable (Figure 2). However, there is no evidence of funnel plot asymmetry, suggesting that publication bias is not a problem despite the lack of "grey literature" regarding the impact of salmonids on amphibians (Figure 3). Anurans and urodeles form distinct subgroups in terms of risk ratios (Figure 2) therefore pooling across all amphibians was considered inappropriate and separate subgroups were pooled.

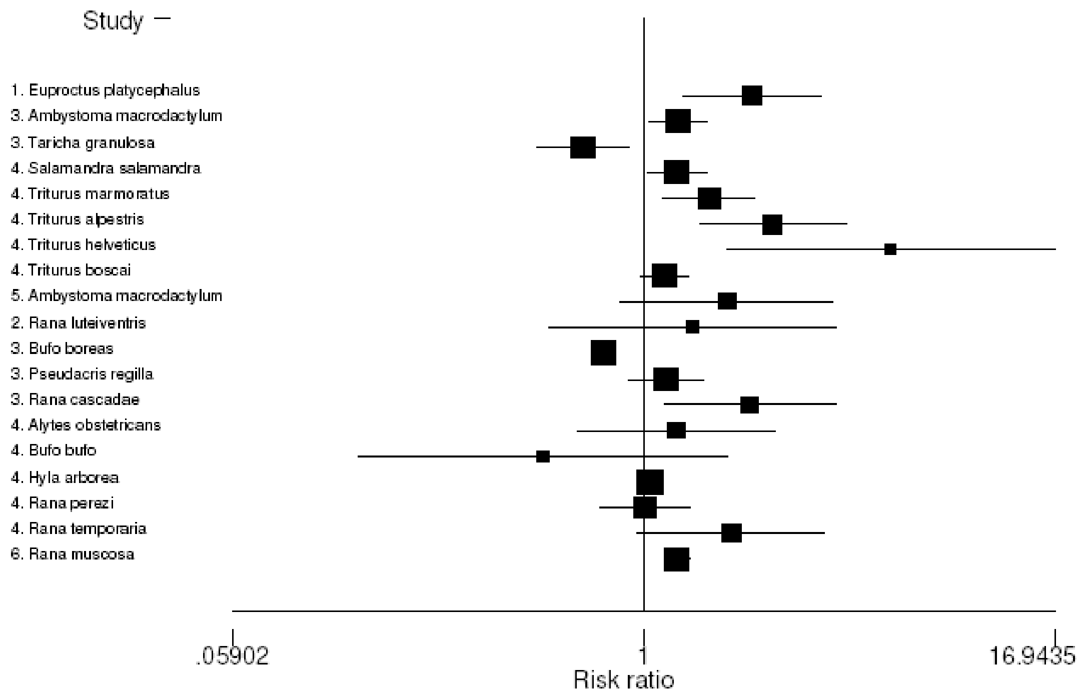

Figure 2: Risk ratios for all amphibian data. Solid boxes represent independent data points. Horizontal lines are 95% confidence intervals. The data are further divided into anurans and urodeles below. Where the risk ratio is> 1 the species is less likely to be present in a water body containing salmonids than in a water body that does not.

Urodele subgroup analysis

The DerSimonian & Laird pooled risk ratio for urodele data, is 1.420 indicating that in general, urodeles are less likely to be present in water bodies that contain salmonids than those that do not (Figure 4). The confidence interval does not cross the line of "no effect" indicating that the result is statistically significant (z=2.94, p=0.003). However, there is significant variation between the individual data points (chi-squared =38.19, df=8, p=<0.001) indicating that urodele species do not have a uniform response to stocking. One species (*Taricha granulosa*; Rough-skinned newt) is more likely to be present in water bodies that contain salmonids than those that do not (Figure 4). The pooled odds ratio (odds ratios compare how likely an event is between two groups) is similarly positive, statistically significant with variation between individual data points (OR 6.5303, z=2.46, p=0.014, chi-squared=34.43, df=8, p=<0.001) suggesting that choice of analytical method is not critical. The pooled risk difference (risk difference compares the risk in terms of an absolute difference, rather than in relative terms) is 0.291 (z=3.07, p=0.002 with significant heterogeneity between individual data points (chi-squared=41.61, df =8, p=<0.001).

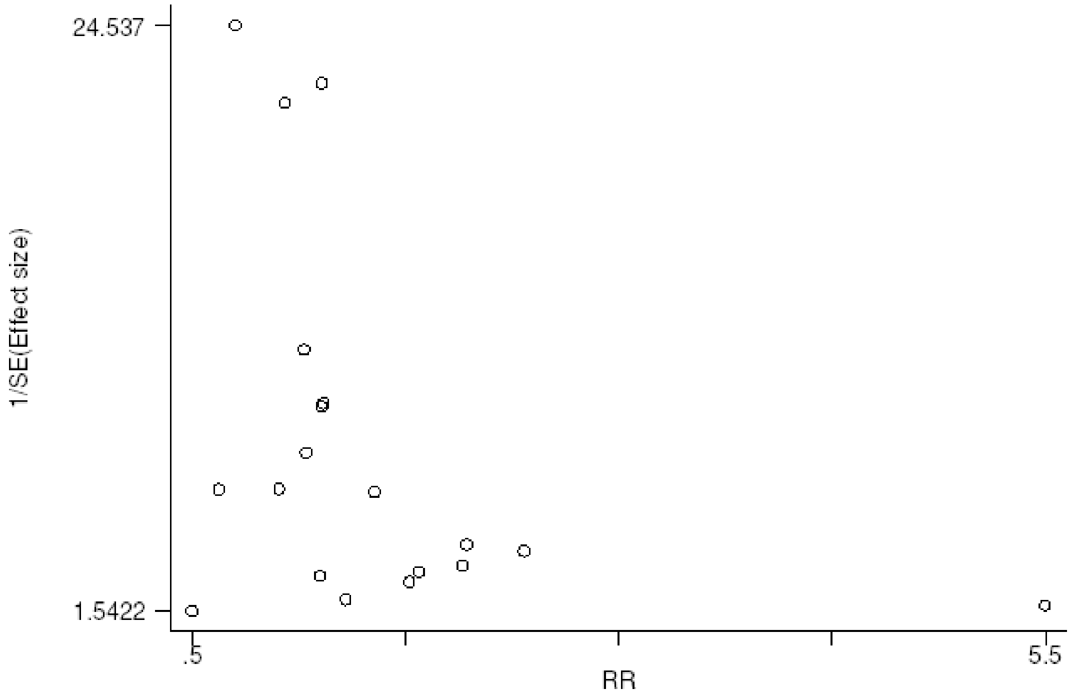

Figure 3: Funnel plot of all amphibian data. The inverse variance of the effect sizes (circles) in relation to the magnitude of the risk ratio (RR). Small studies with large risk ratio's are present but corresponding studies with low risk ratio's are not. This may indicate that small risk ratio's are not as easy to publish as large ones (publication bias) or may be a true reflection of the totality of the data.

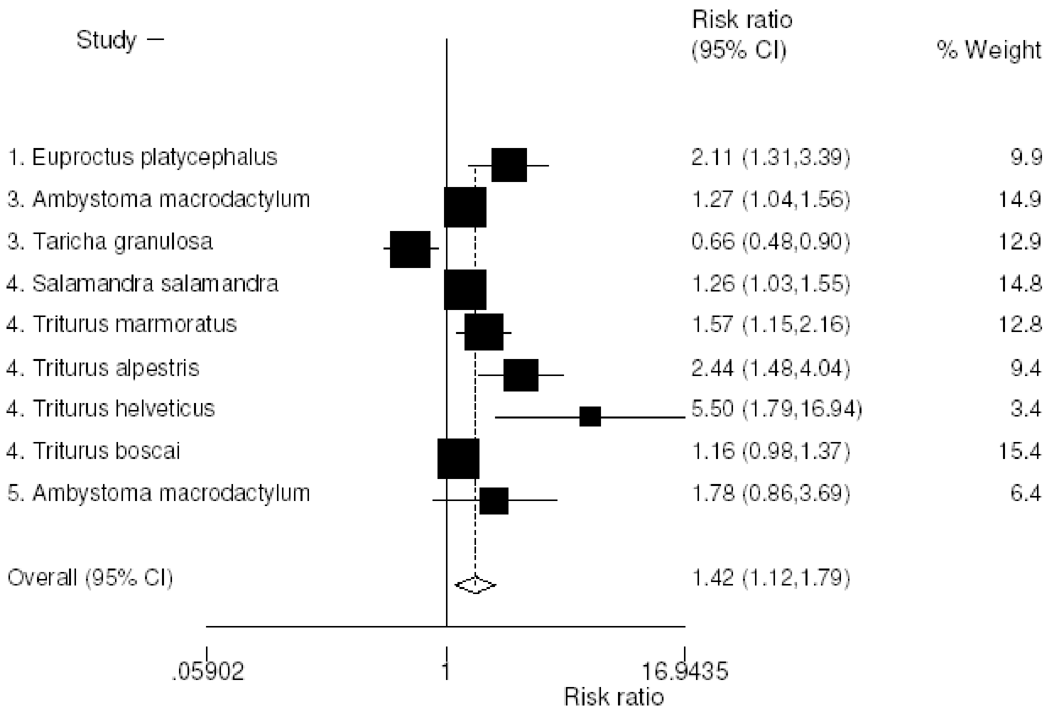

Figure 4: Urodele subgroup risk ratio analysis. Solid boxes represent independent datapoints, with horizontal lines showing 95% confidence intervals. The white diamond represents the pooled risk ratio. Risk ratios and relative weightings of individual points are shown. Where the risk ratio is > 1 the species is less likely to be present in a water body containing salmonids than in a water body that does not.

Anuran subgroup analysis
The DerSimonian & Laird pooled risk ratio for anuran data, is 1.148 but the result is not statistically significant (z=1.08, p=0.282) suggesting that stocking does not have an impact on the occupancy of anurans in general (Figure 5). However, there is significant variation between the individual data points (chi-squared=141.07, df=9, p=<0.001) indicating that anurans species do not have a uniform response to stocking. *Rana cascadae* (Cascades frog) and *Rana muscosa* (Mountain yellow-legged frog) are both significantly less likely to be present in water bodies stocked with salmonids than water bodies which do not, whilst the converse is true for *Bufo boreas* (Western toad) (Figure 5). The pooled odds ratio and risk difference corroborate these results and indicate that the results are not dependent upon analytical method (OR 1.84633, z=1.90, p=0.058, chi-squared=19.94, df=9, p=0.018, RD 0.071, z=0.82, p=0.413, chisquared=100.88, df=9, p=<0.001).

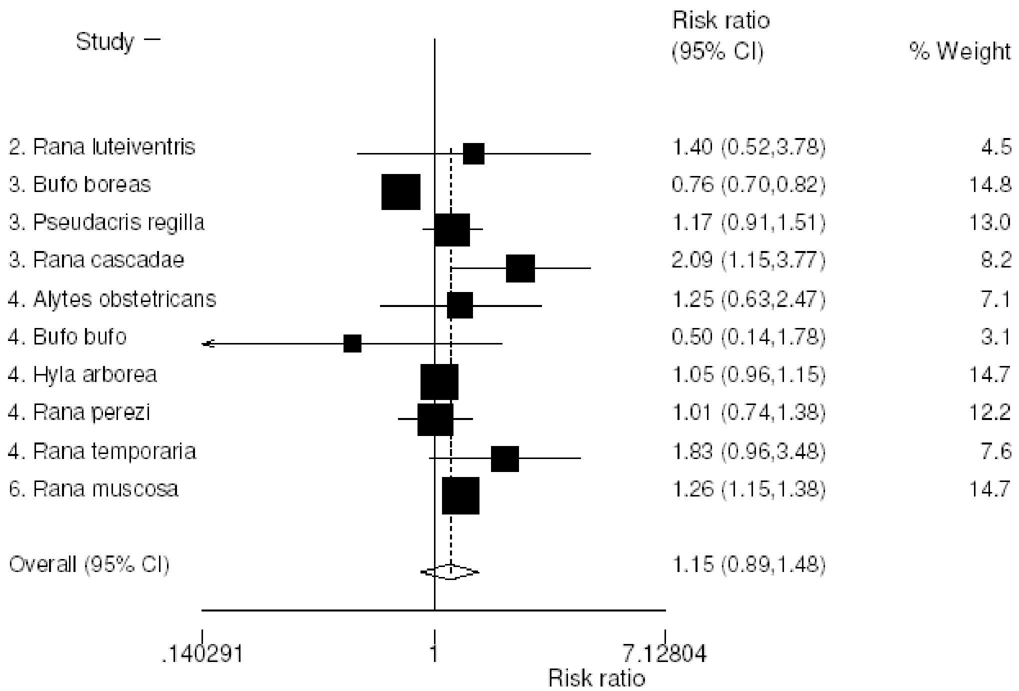

Figure 5: Anuran subgroup risk ratio analysis. Solid boxes represent independent data points, with horizontal lines showing 95% confidence intervals. The white diamond represents the pooled risk ratio. Risk ratios and relative weightings of individual points are shown. Where the risk ratio is > 1 the species is less likely to be present in a water body containing salmonids than in a water body that does not.

4.4 Outcome of the review

4.4.1 Primary Outcomes

The effects of salmonid stocking on native salmonids, other fish and lampreys
Experimental and management methodologies were too diverse for meta-analysis, and sample size was insufficient for robust multivariate analysis of data regarding the effects of salmonid stocking on native species. 89 papers were identified as reporting on impacts on salmonids, other fish and lampreys, behaviour and disease introduction. Due to the

diverse range of outcome measures and methodological techniques these papers do not allow any form of systematic synthesis even including discriminatory vote counting.

The effects of salmonid stocking on herpetofauna
There is evidence of an effect of stocking salmonids in lakes that provide habitat for amphibians. Overall, Urodeles are less likely to be found in water bodies containing salmonids than those that do not contain salmonids. However, species responses vary considerably and there are many factors that could contribute to these differences, such as life histories, habitat preferences, the nature of the stocking and the monitoring methodology. *Taricha granulosa* (Rough-skinned newt) is more likely to be present in water bodies which contain salmonids than those which do not. Overall anuran occupancy in stocked and unstocked water bodies does not differ significantly but *Rana Cascadae* (Cascades frog) and *Rana muscosa* (Mountain yellow-legged frog) are both significantly less likely to be present in water bodies stocked with salmonids than water bodies which do not, whilst the converse is true for *Bufo boreas* (Western toad). *Rana muscosa* is threatened in the Sierra Nevada, where it is absent from much of its historic range and endangered in Southern California, where it is absent from 99 percent of its historic range. The decline has been attributed to bullfrogs, trout, airborne pollution, cattle grazing, ozone depletion, mining pollution, off road vehicle disturbance, public dumping, chytrid fungus, fires, and excessive flooding (http://www.californiaherps.com). Thus the danger of ignoring heterogeneity between individual species, when considering the pooled risk ratio, may have conservation implications.

The effects of salmonid stocking on invertebrates, macrophytes and plankton
No evidence of an effect of stocked salmonids was found on any of the other taxa investigated within this review. No evidence of an effect is different from evidence of no effect and this review demonstrates lack of available data (Tarnow-Mordi and Healy 1999).

There is insufficient reporting of the effects of salmonid stocking on invertebrates to be able to clearly demonstrate any effect on invertebrate populations in lakes. Only nine studies were identified of relevance to the review, of which one contains data suitable for meta-analysis, although the data presented in the paper are incomplete and would only allow reanalysis of the one study findings.

The effects of salmonid stocking on lake macrophytes are not widely reported in the literature. One study, Gee *et al.* (1997), reports no effect of stocked salmonids on macrophyte species richness, however there are insufficient studies to allow metaanalysis.

Regarding the effects of salmonid stock on plankton, again sample size was insufficient for robust multivariate analysis of data. A diverse range of outcome measures and methodological techniques are presented in these papers. Many studies present changes in plankton assemblages over time represented graphically, sometimes combining paleolimnological data with recent population estimates. It is not possible to extract data from these in a meaningful and consistent way. Studies often lack variance or replication. Therefore, there is not a coherent evidence-base regarding the impact of salmonid stocking on plankton.

5. DISCUSSION

Amphibians are sometimes regarded as an indicator species of general environmental health (Bury *et al.* 1995, Collins & Storfer 2003), and therefore the reports of global decline in amphibian numbers over recent decades have created much interest. There are many factors that may be responsible for these declines, one potential causal agent being introduced species. Introduced fish may lead to declines or even extirpation of native amphibians through, for example, competition, predation, or the incidental introduction of disease. Introductions may lead to previously occupied habitat being abandoned, with associated disruption of metapopulation structure, triggering further decline (Pilliod & Peterson, 2001).

It has often been reported that the stocking of nonnative salmonids, has a negative effect on native amphibians, causing reductions in numbers, loss of population diversity (such as loss of paedomorphic newts, DeNoel *et al.* 2005) and even extirpation of local populations. Despite this, there is limited evidence available on the effects of salmonid stocking on herpetofauna. Amphibians are better represented in the literature than reptiles. Most available studies concentrate on presence or absence data. Data obtained in this review shows that salmonid stocking has an effect on some amphibian populations. Available evidence suggests that overall, urodeles are less likely to be found in water bodies containing salmonids than those without, with the exception of *Taricha granulosa* (Rough-skinned newt).

Overall anuran occupancy in stocked and unstocked water bodies does not differ significantly but *Rana Cascadae* (Cascades frog) and *Rana muscosa* (Mountain yellow-legged frog) are both significantly less likely to be present in water bodies stocked with salmonids than water bodies which do not, whilst the converse is true for *Bufo boreas* (Western toad). Other empirical data concerning amphibians was available (Kiesecker *et al.* 2001) but did not allow derivation of risk ratios. This paper concurred with the current analysis, indicating that survival to hatching was greater in waters that did not contain introduced rainbow trout.

5.1 Review limitations

One of the main limitations that effects studies concerned with historical actions such as fish stocking is the lack of baseline data. Often studies attempt to quantify the impacts of stocked salmonids after the stocking event has taken place, and for this reason the study design is restricted. This means that there is a lack of before/after data available, and often there is no control or replication possible. This results in studies presenting data often not suitably robust to allow a rigorous data extraction and meta analysis.

A large proportion of the literature accepted for full text assessment comprised review and discussion articles and little primary data. Many included studies present no variance measures or incomplete data, and although further data may be obtainable from the authors, thus potentially allowing meta-analysis, the sample size is likely to still be small. Studies use a diverse range of methodologies and presentation measures, reducing comparability of the data sets. An example if this is in the amphibian presence/absence studies, where results are presented as percentage water body surface area, number of water bodies, percentage of complete water bodies, and statistical significance of values.

Often the quantity of literature yielded from the searches is misleading; software compatibility shortcomings (i.e. a failure to import full records properly with some electronic resources), and a lack of abstracts being available meant that many items were included by default. Another important issue is the lack of clarity in abstracts and key words, which means that it is often unclear whether the fish being investigated are salmonids until articles are viewed at full text, and whether the environment in which the study had been carried out was relevant to lakes or rivers.

6. REVIEWERS' CONCLUSIONS

6.1 Implications for conservation management

Available evidence suggests that lakes into which salmonids have been introduced are less likely to contain newts or salamanders than those which contain no salmonids. A precautionary approach to stocking with salmonids is necessary if potentially deleterious impacts to anuran populations are to be avoided. However, there is unexplained species- or study-specific variation and *Taricha granulosa* (Rough-skinned newt) is more likely to be present in water bodies that contain salmonids than those which do not.

The impact of stocking on frogs and toads is variable, but overall, available evidence suggests that stocked lakes are as likely to contain them as unstocked lakes. In general, they therefore appear less vulnerable to stocking than newts and salamanders. However, *Rana cascadae* (Cascades frog) and *Rana muscosa* (Mountain yellowlegged frog) are both significantly less likely to be present in water bodies stocked with salmonids than water bodies which do not. The latter is of conservation concern and a precautionary approach to stocking with salmonids is necessary if potentially deleterious impacts to *R. cascadae* and *R. muscosa* populations are to be avoided.

There is no evidence available to demonstrate any other effects of stocked salmonids on the ecosystem. Conservation managers must consider habitat use by amphibians when contemplating salmonid introductions, especially in cases where amphibian conservation is a priority.

6.2 Implications for fisheries management

When stocking lakes for fisheries, it is important that the presence of amphibian species is taken into consideration during environmental impact assessment.

6.3 Implications for further research

Further research is required regarding the effects on lake biota, both direct and indirect, of introducing salmonids, as high level predators. Studies should aim to have a comparator or measure before and after stocking incidents, and where possible, replication. Monitoring of stocking programmes should be carried out, particularly in previously un-stocked or fishless lakes, and outcomes should be more widely reported. Wherever possible, pre-stocking measurements of species and numbers should be made for future comparisons.

Ecologists should be wary of citing the abundant literature regarding the impact of salmonid stocking, without careful perusal of results. Many of the conclusions presented in the existing literature are largely speculative, or based on river and stream habitats, which may not respond to stocking in the same manner as lakes.

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8. POTENTIAL CONFLICTS OF INTEREST AND SOURCES OF SUPPORT

No potential conflicts if interest reported. Financial support from NERC

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10. Appendices

Appendix 1 – Summary of salmonid stocking impacts reported in the literature

AREA	SPECIES	REFERENCE	COMMENT	SUBJECT	TREATMENT	OUTCOME
Biota	Amphibians, reptiles, benthic macroinvertebrates and zooplankton	Knapp *et al* (2005)	Compare observed/expected ratios of biota in lakes which were stocked and have since lost fish populations	Yosemite National Park	Salmonid stocking	Multiple - presence and absence data
Biota	Amphibians, reptiles, benthic macroinvertebrates and zooplankton	Knapp *et al* (2001)	Study compares the effects on biota in stocked and never stocked lakes	Sierra Nevada	Salmonid stocking	Population presence and abundance
Biota	Amphibians, reptiles, benthic macroinvertebrates and zooplankton	Knapp *et al* (2005)	Use observed/expected ratios to assess abundance of biota in stocked lakes	Yosemite National Park lakes	Salmonid stocking	Distribution of amphibians
Biota	Invertebrates and zooplankton	Gloss *et al* (1989)	Stocked brook trout diet	Adirondack Mountain lakes	*Salvelinus fontinalis*	Diet composition
Biota	Macrophytes and invertebrates	Gee *et al* (1997)	Compares ecology of 51 ponds in Wales, of which several have been stocked.	Ponds in Wales	Salmonid stocking	Change in biodiversity
Biota	Multiple	Dick *et al* (1987)	Stocked fishes introduced a parasite which effected not only the trout but other fishes and also birds	High Rock Lake, Manitoba	*Oncorhynchus mykiss*	Parasite numbers
Biota	Multiple	Eby *et al* (2006)	Discussion paper on introduction of high level predators in aquatic food-webs	Freshwater food webs	Salmonids and other fishes	Multiple
Biota	Multiple	Fraley, J. (1996)	Discussion on wilderness management, in particular stocking.	Wilderness lakes	Stocking, other management techniques	Potential outcomes to biota

Biota	Multiple	Jackson *et al* (2004)	Effects of stocked salmonids in Australia, may contain useful references, mentions rivers.	Australian waterways	*Salmo trutta* and *Oncorhynchus mykiss*	Potential damage to other, native, species
Biota	Multiple	Mills *et al*(2003)	Presents stocking numbers over time as one aspect of the Lake Ontario food web	Lake Ontario	Salmonids	Phosphorus loading,biomasses and relative abundances
Biota	*Oncorhynchus mykiss* and *Salmo trutta*	Cadwallader and Eden (1981)	Discusses stocking salmonids and an emerging preference to stock Australian natives in reservoirs in Australia and New Zealand	Reservoirs of Australia and New Zealand	Stocking *Oncorhynchus mykiss* and *Salmo trutta*	Effects and costs
Biota	Other fish including salmonids, crayfish	Thiede *et al* (2000)	Look at effect of introduced lake trout on food chain, express predation in metric tonnes	Lake Tahoe, Sierra Nevada	Lake trout *Salvelinus namaycush*	Predation
Fish	Arctic charr *Salvelinus alpinus*	Damsgard and Langeland (1994)	Measure predation of stocked Brown trout, raised on either fish or pellet diets, on Arctic char	Noway	*Salmo trutta*	Piscivory and growth
Fish	Coho Salmon	Bonar *et al* (2005)	Looks at the effects of introduced fishes (including salmonids) on Coho salmon, including predation	Western Washington Watersheds	*Oncorhynchus mykiss* and *Oncorhynchus clarki*, plus other non-salmonids	Predation- bass more likely to be damaging than other salmonids
Fish	Disease	McVicar (1997)	Discusses effects of interactions between wild and cultured Atlantic salmon and pathogen transfer	All	*Salmo salar*	No data, discussion of disease transfer
Fish	Disease	Rahkonen and Koski (1997)	Study disease prevalence in stocked fishes in a reservoir and their prey	Lake Inari, Finland	*Salmo trutta*	Disease prevalence
Fish	Fish	Bronte *et al* (2003)	Looks at changes in the fish community over time in response to introductions of other species and diseases.	Lake Superior	Stocking of fishes including salmonids	Estimated consumption of prey items

Fish	Fish	Crivelli (1995)	Looks at geographically widespread impact of introduced species on native freshwater fishes in the Mediterranean, including hybridisation	Mediterranean region	Brown and marbled trout and others	No salmonid data presented
Fish	Fish	Dobiesz *et al* (2005)	Reviews fluctuations in Lake Huron fish communities over 29 years	Lake Huron	*Salvelinus namaycush*	Yield, biomass etc of fishes
Fish	Fish	Hyvarinen and Huusko, (2005)	Looks at impact of native fishes on stocked salmonids in a coastal lake	Lake Oulujarvi	*Salmo trutta*	Predation
Fish	Fish	Sprules *et al* (1991)	Look at assemblages in Lake Michigan and prey availability for salmon	Lake Michigan	Salmon	Diet composition
Fish	Fish	Vehanen, Hyvarinen and Huusko (1998)	Fish consumption by stocked brown trout and pikeperch including diet composition and prey orientation	Lake Oulujavi, Finland	Brown trout, *Salmo trutta*, and pikeperch, *Stizostedion lucioperca*	Predation
Fish	Fishes	Krueger and May (1991)	Discussion on effects of salmonid stocking, ecological but also genetic effects	North America	Introduced salmonids	Multiple
Fish	*Lepidomeda vittata*	Sweester (2002)	Looks at impact of introduced salmonids on a fish species of conservation concern	Eastern Arizona	*Oncorhynchus mykiss*	Location, stomach contents
Fish	Mexican native trout	Hendrickson *et al* (2002)	Discusses impacts on Mexican native trout, including the effects of introduced rainbow trout	Mexico	*Oncorhynchus mykiss*	Competition and genetic impacts
Fish	Multiple	Elvira and Almodovar (2001)	Discussion on fish introductions in Spain, includes salmonids.	Spanish waters	Introduced fishes	Potential competition with native fish species

Fish	Native fishes	de Jong *et al* (2004)	Discuss the competition, predation and disease impacts of fish introductions in Labrador and Newfoundland on native fishes, as well as genetic	Labrador and Newfoundland	Introduced fishes	competition, predation and disease
Fish	Non-salmonids	Hartleb (1996)	Impact of stocked salmonids on native fish diet and behaviour	Maine ponds	*Salvelinus fontinalis*	Feeding behaviour
Fish	Non-salmonids	Johnson (1983)	Predation by stocked Chinook salmon in Lake Ontario	Lake Ontario	*Oncorhynchus tshawytscha*	Predation
Fish	Oncorhynchus clarki	Dunham *et al* (2002)	Reviews the impacts in the literature of Brook trout on Cutthroat trout	Western USA	*Salvelinus fontinalis*	-
Fish	Oncorhynchus clarki	Quist and Hubert (2004)	Look at the impact of stocked salmonids on a native salmonid	Western United States	Stocked salmonids	Multiple
Fish	*Oncorhynchus clarki bouvieri*	Kaeding *et al* (1996)	Introduced lake trout thought to threaten native Cutthroat trout	Yellowstone Lake	*Salvelinus namaycush*	Competition or predation
Fish	*Oncorhynchus clarki bouvieri*	Stapp and Hayward (2002)	Look at the predation of a native salmonid by stocked lake trout	Yellowstone Lake	*Salvelinus namaycush*	Predation
Fish	Oncorhynchus mykiss	Yule *et al* (2000)	Comparison of different strains of stocked rainbow trout, angler success and predation by walleyes.		*Oncorhynchus mykiss*	Predation by walleyes Stizostedion vitreum, strain success
Fish	*Perca fluviatilis* and *Salmo trutta*	Molony, B. W., Bird, C. and Nguyen, V. P. (2004)	As unitentional food source for other fishes	Lake Navarino, Australia	*Oncorhynchus mykiss*	Predation of stocked fish
Fish	*Petromyzon marinus*	Young *et al* (1996)	Increase in sea lamprey due to increased prey abundance correlated to stocking effort	Lake Huron and tributary	lake trout (S*alvelinus namaycush*) and chinook salmon (*Oncorhynchus tshawytscha*)	Lamprey predation

Fish	*Salmo salar*	Hansen *et al* (1997)	Discussion of interactions between wild and cultured Atlantic salmon	All	*Salmo salar*	Multiple
Fish	*Salmo salar*	Heggberget *et al* (1993)	Discusses the potential interactions between wild and cultured salmon	All	*Salmo salar*	diseases and genetic effects
Fish	*Salmo salar*	Saunders (1991)	Possible interactions between wild and cultured Atlantic salmon	All	*Salmo salar*	Disease, parasites, behavior-ecology and genetics
Fish	*Salmo salar*	Scott *et al* (2005)	Looks at nest counts as evidence of reproduction	Ontario tributary	*Salmo salar*	Nest counts
Fish	*Salmo trutta*	Bohlin *et al* (2002)	Looks at the effects of density on growth in wild resident, wild introduced and hatchery Salmo trutta	Salmo trutta	*Salmo trutta*	Growth and survival
Fish	*Salmo trutta*	Ferguson (2004)	Discusses impacts on native species of threats including Brown trout stocking	Irish loughs	*Salmo trutta*	-
Fish	Salmonids	Einum and Fleming (2001)	Review of interactions between wild and released salmonids	Any habitats	Salmonids	Agression and predation
Fish	Salmonids	Graynoth (1987)	Comparison of stocked and now resident *Onchorynchus nerka* growth rates	Waitaki Lakes, New Zealand	*Oncorhynchus nerka*	Comparison of growth rates
Fish	Salmonids	Heuch *et al* (2005)	Lice- transfer to wild populations and effect of National Plan to control this	Norway	Salmonids	Disease transfer
Fish	Salmonids	Jonsson and Jonsson (2006)	Look at competitiveness of cultured salmonids compared with wild counterparts.	All	*Salmo salar*	behavioural and physiological
Fish	Salmonids	Kahilainen & Lehtonen (2001)	Looks at habitat use, growth and prey consumption by native and stocked salmonids	Lake Muddusjarvi, Finland	Stocking *Salmo trutta*	Habitat, growth and diet
Fish	Salmonids	Kahilainen & Lehtonen (2002)	Looks at habitat use, growth and prey consumption by native and stocked salmonids	Lake Muddusjarvi, Finland	Stocking *Salvelinus alpinus*	Habitat, growth and diet

Fish	salmonids	L'abee-Lund *et al* (1992)	Looks at competition between wild and stocked brown trout and arctic char	Lake Tunhovdfjorden, Norway	*Salvelinus alpinus* and *Salmo trutta*	Habitat use and feeding habits
Fish	Salmonids	Oconnell and Gibson (1989)	Maturation of female anadromous Atlantic salmon in a land-locked pond compared with normal conditions	Pond in Newfoundland, Canada	*Salmo salar fry*	Growth rates and maturation
Fish	Salmonids	Ogrady (1983)	Comparison of diet in stocked, wild and established brown trout	Irish lakes	*Salmo trutta*	Diet composition
Fish	*Salvelinus alpinus*	Brown *et al* (1992)	Looks at the effect of density on behaviour and growth rates	Various	*Salvelinus alpinus*	Growth
Fish	*Salvelinus namaycush*	Savino *et al* (1993)	Predation of young lake trout by juveniles of wild and hatchery origin	Tanks	*Salvelinus namaycush*	Predation and feeding ability
Fish	*Salvelinus namaycush*	Sitar *et al* (1999)	Discusses attempts to restore lake trout to Lake Huron	Lake Huron	*Salvelinus namaycush*	Lamprey predation, survival- modelling paper
Fish	Sea lamprey *Petromyzon marinus*	Jorgensen and Kitchell (2005)	Stocked salmonids act as hosts for sea lampreys in Lake Superior, causing martality of stocked fishes.	Lake Superior	*Onchorhynchus sp*	Mortality from parasitism of stocked fishes
Fish	Sockeye salmon *Oncorhynchus nerka*	Baldwin *et al* (2003)	Look at the predation of stocked fish by walleye	Lake Roosevelt	sockeye salmon *Oncorhynchus nerka*	Predation by walleye
Fish	Introduced trout	Crivelli *et al* (1997)	fish pops many from introduced species	Prespa Lakes	Introduced species	Yields and threat to endemic fishes
Fish	Disease	Kennedy *et al* (1991)	Study looks at helminth populations and stocking patterns in English reservoirs	English reservoirs	brown trout *Salmo trutta* and rainbow trout *Oncorhynchus mykiss*	Transition of helminth parasites
Fish	salmonids	Lachance and Magnan (1990)	Effect of native fishes on wild, hatchery and hybrid brook trout and their relative survival	small oligotrophic lakes of the Laurentian Shield	*Salvelinus fontinalis*	Yield

Herpetofauna	*Ambystoma tigrinum*	Olenick and Gee (1981)	Looks at dietary overlap between tiger salamanders and stocked trout	Manitoba prairie pothole lakes	*Oncorhynchus mykiss*	Diet composition
Herpetofauna	Amphibians	Collins and Storfer (2003)	Reviews the main hypotheses surrounding amphibian declines	Global	Multiple	Amphibian decline
Herpetofauna	Amphibians	Gardner (2001)	Overview of amphibian decline and future directions	Global	Multiple	Amphibian decline
Herpetofauna	Amphibians	Kats and Ferrer (2003)	Review of studies on alien predators and amphibians, includes salmonids	Global	Alien predators including fishes	Decline and recovery
Herpetofauna	Amphibians	Orizaolo & Braña (2006)	Compared presence of amphibians with introduced fishes	northern Spain	Introduced species	Distribution and abundance
Herpetofauna	Amphibians	Storfer (2003)	Reviews amphibian declines and discusses future actions.	All	Includes stocking	Amphibian decline
Herpetofauna	Columbia spotted frog *Rana luteiventris*	Reaser (2000)		Toiyabe Range, Nevada	Trout	recruitment, survival and mortality
Herpetofauna	Iberian frog *Rana iberica*	Bosch *et al* (2006)	Look at occurrence of Iberian frog in terms of available habitat and stocked salmonids	central Spain	*native brown trout (*Salmo trutta*) and exotic brook trout (*Salvelinus fontinalis*)*	distribution
Herpetofauna	Long toed salamander *Ambystoma macrodactylum* & Columbia spotted frogs *Rana Luteiventris*	Pilliod and Peterson (2001)	Suggests that trout introductions may remove valuable habitat and so fishless sites will also decline	Frank Church-River of No Return Wilderness, Idaho	introduced trout	Densities and habitat features
Herpetofauna	Long-toed salamander *Ambystoma macrodactylum*	Funk and Dunlap (1999)	Stocked fish presence, extinction and recolonisation by salamanders	Bitterroot Mountains of Montana, U.S.A.	Trout	Presence or absence

Herpetofauna	Long-toed salamander *Ambystoma macrodactylum*	Tyler *et al* (1998)	Looks at presence of salamanders and introduced trout in a National Park Complex.	North Cascades National Park, Washington, USA	Introduced trout	Presence or absence of salamanders
Herpetofauna	Long-toed salamander *Ambystoma macrodactylum*	Tyler *et al* (1998)	Stocked trout and larval salamander interactions	North Cascades National Park, Washington, USA	Introduced trout	
Herpetofauna	Mountain yellow legged frog *Rana mucosa,* Pacific treefrog *Hyla regilla*, Yosemite toad *Bufo canorus* and Sierra newt *Taricha torosa* Sierra Mountain garter snake *Thamnophis elegans elegans*, Sierra garter snake *Thamnophis couchi couchi*	Knapp (2005)	Uses habitat and population data in generalised additive models to determine effects of introduced trout on amphibians	Yosemite National Park, USA	Non native trout	Distribution of reptiles and amphibians
Herpetofauna	Mountain ye*llow legged frog, Rana mucosa*	Bradford *et al* (1993)	Reduction in population in sites with and without fish attributed to loss of habitat networks	Sequoia and Kings Canyon National Parks, California	Introduced trout	Presence and abundance
Herpetofauna	Mountain yellow-legged frog, *Rana mucosa*	Knapp and Matthews (2000)	Correlates water body surface area containing trout with surface area containing frogs.	California's Sierra Nevada	Introduced trout	Occupied water body surface area
Herpetofauna	Northern dusky Salamanders *Desmognathus fuscus fuscus*	Bank *et al* (2006)	Compare current and historic abundance of the salamander	Acadia National Park, Maine, USA	Introduced trout	Presence at sites in historic range
Herpetofauna	Paedomorphic newts	DeNoel *et al* (2005)	Found paedomorph populations extitpated in fish stocked sites	France, Italy, Slovenia, Bosnia, Montenegro, and Greece	Exotic fishes including salmonids	presence or extirpation

Herpetofauna	Ranid frogs	Jennings (2005)	Discussion of ranid frogs in California	California	Introduced fishes	Abundance and decline
Herpetofauna	Sardinian newt *Euproctus platycephalus*	Lecis and Norris (2003)	Presence of Sardinian newt compared with habitat variables	Sardinia	Introduced trout	habitat characteristics and newt occurrence and persistence
Herpetofauna	Sub-alpine amphibians	Welsh *et al* (2006)	Correlates introduced salmonids with presence of palatable and non-palatable amphibians	Klamath mountains of northern California	Introduced trout	Correlation with fish presence
Herpetofauna	Western toad *Bufo boreas*	Kiesecker *et al* (2001)	Looks at pathogen transfer from introduced rainbow trout Oncorhynchus mykiss	Cascade Mountains of Oregon, U.S.A	Oncorhynchus mykiss	Pathogen transfer
Invertebrates	Chaoborus	Lamontagne (1993)	Paleolimnological analysis of Chaoborus to determine whether fish were native or introduced.	Lakes in Jasper National Park	Includes *Oncorhynchus mykiss*	Changes in Chaoborus populations
Invertebrates	Chaoborus	Lamontagne. and Schindler (1994)	Paleolimnological analysis of Chaoborus to determine whether fish were native or introduced.	Lakes in Jasper National Park	Includes *Oncorhynchus mykiss*	Changes in Chaoborus populations
Invertebrates	Mayfly *Callibaetis ferrugineus*	Caudill (2005)	Use statistical methods to assess changes in mayfly populations	12 Rocky Mountain beaver ponds	*Salvelinus fontinalis*	Changes in mayfly metapopulation
Plankton	Algae	Schindler *et al* (2001)	Looks at changes in phosphorus cycling and algal production	Mountain lakes in Sierra Nevada	Salmonids	Phosphorus loading, biomasses & CPUE data
Plankton	Cladocera	Gliwicz (1980)	Use sediment record to chart changes to plankton assemblages in mountain lakes stocked with salmonids	Tatra Lakes, Europe	Salmonid introduction	Extinction of plankton
Plankton	Cladocera and algae	Miskimmin *et al* (1995)	Use sediment cores to study cladoceran and algal assemblages to determine impact of stocking and toxaphene application.	Two Canadian lakes	Toxaphene application and trout stocking	Changes in cladoceran and algal assemblages

Plankton	Copepods	Liss *et al* (1998)	Looks at the influence of naturally reproducing and stocked salmonids on diaptomid copepods	High elevantion lakes in Washington	Trout - Cutthroat and Rainbow	Abundance, distribution and maximum summer densities of diaptomid copepods
Plankton	*Cyclops abyssorum tatricus*	Gliwicz and Rowan (1984)	Looks at survival of the Cyclops in a stocked lake	Tatra Lakes, Europe	Salmonid introduction	Depth distributions and egg abundance of Cyclops
Plankton	*Daphnia*	Hembre and Megard (2005)	Study looks at the effect time of stocking has on Daphnia populations	Long Lake	*Oncorhynchus mykiss*	Size, monthly distribution, stomach contents etc
Plankton	*Daphnia*	Membre and Megard (2005)	Looks at the effects of predation on Daphnia and the subsequent effect on grazing of phytoplankton.	Minnesota lake, USA	*Oncorhynchus mykiss*	Effects on (and of) Daphnia
Plankton	*Daphnia*	Saegrov *et al* (1996)	Looks at the role of size and pigmentation in prey selection by Brown trout	Bjornesfjorden, Norway	*Salmo trutta*	Daphnia levels
Plankton	*Daphnia*	Seda *et al* (2000)	Look at nine reservoirs, of which only two included salmonids amongst fish stocked	Czech reservoirs	Fishes including *Salmo trutta*	Daphnia levels
Plankton	*Daphnia*	Tabor *et al* (1996)	Daphnia in the diet of stocked rainbow trout	Utah reservoirs	*Oncorhynchus mykiss*	Diet composition
Plankton	*Daphnia*	Winder *et al* (2004)	Studied diel migration using cyprinids and enclosure experiments with salmonids	Oberer Arosasee, Swiss high mountain lake	*Salmo trutta* (juvenile)	Daphnia and other zooplankton abundance
Plankton	*Daphnia*	Wissell *et al* (2000)	Stocking piscivorous fish to control planktonivorous fishes as food web biomanipulation	Two lakes	*Oncorhynchus mykiss*	Daphnia levels
Plankton	*Daphnia spp.*	Verschuren and Marnell (1997)	Historic analysis of impact on trout stocks on fossil zooplankton to determine origin of trout	headwater lakes of Glacier National Park	westslope cutthroat trout *Oncorhynchus clarki lewisi*	Daphnia population changes

Plankton	Diatoms	Drake (2000)	Uses paleolimnological cores to compare before, during and after the presence of introduced trout	Mt. Rainier National Park, USA	Trout	Changes in diatom assemblages
Plankton	Diatoms	Drake and Naiman (2000)	Use paleolimnological analysis of cores to determine population fluctuations within historically stocked lakes	Lakes in Mt Rainier National Park, WA, USA	Salmonid stocking	Diatom assemblages over time
Plankton	*Hesperodiaptomus arcticus*	Parker *et al* (1996)	Use current and historical data to determine effect on copepods of fish stocking episodes	Snowflake and Pipit lakes	Salmonids stocked	Copepod presence or abundance
Plankton	macrozooplankton	Kyle (1996)	Looks at 13 barren lake systems before and after stocking	Alaskan barren lake systems	*Oncorhynchus nerka* (fry)	Number and biomass of macrozooplankton
Plankton	Phytoplankton	Carpenter *et al* (1993)	Look at the effect of stocked fish and their removal on phtoplankton assemblages	Wisonsin Lakes	*Oncorhynchus mykiss* and non salmonid *Notemigonus crysoleucas*	Phytoplankton assemblages
Plankton	Phytoplankton	Leavitt *et al* (1994)	Paleolimnology and other methods used to assess impacts of stocking trout on a previously fishless lake, using another local lake as a control	Alpine lakes in the Canadian Rocky Mountains	Brook (*Salvelinus fontinalis*), Cutthroat (*Oncorhynchus clarkii*) and Rainbow trout (*O. mykiss*)	Change in plankton community structure
Plankton	Plankton	Bukaveckas and Shaw (1997)	Annual stocking and chemical treatment were carried out to restore a lake, resulting in changes in plankton assemblage	Woods Lake	Brook trout (*Salvelinus fontinalis*)	Zooplankton and phytoplankton abundance
Plankton	Plankton	Johannsson (1987)	Looks at zooplankton communities over time in a stocked Lake	Lake Ontario	Salmonids	Zooplankton abundance and biomass

Plankton	Plankton	Larson *et al* (2002)	Study on a stocked lake containing no planktonic crustaceans compared with other surrounding lakes now and just after stocking.	Mowich Lake, Mt Rainier National Park, USA	*Oncorhynchus nerka*	Change in plankton community structure
Plankton	Plankton	McNaught *et al* (1999)	Charts densities of plankton communities over time.	Snowflake Lake, Banff National Park	Trout introduction	Change in plankton community structure
Plankton	Plankton	Parker *et al* (2001)	Studies the effects of fish stocking but also removal on planktonic communities	Fishless alpine lakes	*Salvelinus fontinalis*	Abundance and biomass of plankton
Plankton	Rotifers	Svensson and Stenson (2002)	Study the effects off brown trout stocking and liming on rotifers and the trophic cascade	Lake Gardsjon	*Salmo trutta*	Changes in assemblages and rotifer community
Plankton	Zoolankton	Elser *et al* (1995)	Halted stocking and monitored effect before and after on zopoplankton and ecosystem	Castle Lake	*Oncorhunchus mykiss*	Biomass, diet content, water chemicals etc
Plankton	Zoolankton	Mazumder and Edmundson (2002)	Effects of stocking on daphnia etc	Packers Lake, Alaska	sockeye salmon (*Oncorhynchus nerka*)	Zooplankton abundance, sockeye fry abundance
Plankton	Zooplankton	Bouvet and Chacornac (1986)	Investigates the diet of stocked salmonids in a nutitionally poor lake. In French with English summary.	Lac du Brevent, French Alps	*Onchorhynchus mykiss, Salmo trutta, Salvelinus alpinus* and *Salvelinus fontinalis*	Diet composition
Plankton	Zooplankton	Carlisle and Hawkins (1998)	Experimental stocking of salmonids in combination in order to determine the effects on zooplankton	Utah mountain lakes	Cutthroat and Brook trout	Change in zooplankton abundance and assemblage
Plankton	Zooplankton	Donald *et al* (2001)	Study of the relationship between fish stocking histories in lakes and zooplankton assemblages	Lakes in western Canadian mountain parks	Stocking with fishes including Rainbow trout	Changes in zooplankton assemblages

Plankton	Zooplankton	Stenson and Svensson (1995)	Stocking in a fishless lake which has been treated by liming, and the effects on zooplankton	Lake Gardsjon	Brown and rainbow trout	Zooplankton community structures

APPENDIX 2 - DATA PRESENTED FOR AMPHIBIAN PRESENCE/ABSENCE

REFERENCE:	Lecis and Norris 2003		
SALMONID:	FISH		
HERPETOFAUNA:	Sardinian newt *Euproctus platycephalus*		
LOCATION:	Sardinia, Italy		
N=	22		
EXTRACTION:	Data read from figure 6 p.311		
		FISH	
AMPHIBIAN		**PRESENCE**	**ABSENCE**
	PRESENCE	**0**	**10**
	ABSENCE	**3**	**9**

REFERENCE:	Pilliod and Peterson 2000		
SALMONID:	Introduced trout and sport fish		
HERPETOFAUNA:	Columbia spotted frog *Rana luteiventris*		
LOCATION:	Pacific Northwest		
N=	73		
EXTRACTION:	Data taken from figure 1p p.332 – low and high frog densities combined to give binary presence or absence data.		
		FISH	
AMPHIBIAN		**PRESENCE**	**ABSENCE**
	PRESENCE	**32**	**27**
	ABSENCE	**9**	**5**

REFERENCE:	Welsh *et al* 2006
SALMONID:	Introduced trout
HERPETOFAUNA:	*Rana cascadae, Ambystoma macrodactylum, Pseudacris regilla, Bufo boreas, Taricha granulosa*

Location:	Klamath-Siskiyou Bioregion, N. California, USA
n=	218
Extraction:	Data extracted from table 1 and fig 2 p. 303 – figures calculated from proportions of 218 water bodies as presented in Table 1 and Figure 2. Data for Rana cascadae larvae data not included as post-metamorphs chosen to reflect viable populations.

Amphibian		**Fish Presence**	**Absence**
Rana cascadae post-metamorphs	**Presence**	**73**	**19**
	Absence	**118**	**8**
Ambystoma macrodactylum	**Presence**	**2**	**6**
	Absence	**189**	**21**
Pseudacris regilla	**Presence**	**34**	**8**
	Absence	**157**	**19**
Bufo boreas	**Presence**	**46**	**0**
	Absence	**145**	**27**
Taricha granulosa	**Presence**	**107**	**9**
	Absence	**84**	**18**

Reference:	Orizaola and Braña 2006
Salmonid:	Introduced salmonids
Herpetofauna:	Anurans: *B.bufo, A. obstetricans, R. temporaria, R. perezi and H. arborea,* Urodeles: *T. marmoratus, T. alpestris, T. helveticus, T. boscai, S. salamandra*
Location:	Northern Spain
n=	30
Extraction:	Data extracted from figures 1 a and b, p.3

Amphibian		**Fish Presence**	**Absence**
Bufo bufo	**Presence**	**6**	**11**

	Absence	**2**	**11**
Alytes obstetricans	**Presence**	**3**	**11**
	Absence	**5**	**11**
Rana temporaria	**Presence**	**2**	**13**
	Absence	**6**	**9**
Rana perezi	**Presence**	**1**	**3**
	Absence	**7**	**19**
Hyla arborea	**Presence**	**0**	**1**
	Absence	**8**	**21**
Triturus marmoratus	**Presence**	**0**	**8**
	Absence	**8**	**14**
Triturus alpestris	**Presence**	**0**	**13**
	Absence	**8**	**9**
Triturus helveticus	**Presence**	**2**	**19**
	Absence	**6**	**3**
Triturus boscai	**Presence**	**0**	**3**
	Absence	**8**	**19**
Salamandra salamandra	**Presence**	**0**	**5**
	Absence	**8**	**17**

Reference:	Tyler *et al* 1998
Salmonid:	Introduced trout
Herpetofauna:	Long-toed salamander *Ambystoma macrodactylum*
Location:	North Cascades National Park Service Complex, Washington, USA.
n=	17
Extraction:	Values taken from Table 1, page 98. Values combined across columns to provide binary presence/absence data.

Fish

Amphibian		**Presence**	**Absence**
	Presence	**1**	**4**
	Absence	**8**	**4**

Reference:	Knapp *et al* 2001
Salmonid:	Trout
Herpetofauna:	Mountain Yellow Legged Frog *Rana muscosa*
Location:	Sierra Nevada, E California, USA
n=	504
Extraction:	Data extracted from Fig 2a, p.408. Data read from graph with associated error. Values calculated back from percentages based on values given. Data ectracted from never stocked ("control") and stocked- fish present ("treatment"). Stocked now fishless not extracted.

		Fish	
Amphibian		**Presence**	**Absence**
	Presence	**23**	**58**
	Absence	**266**	**157**