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Research Article

Incorporating invasive alien species into ecological assessment in the context of the Water Framework Directive

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Abstract

The Water Framework Directive (WFD) is currently the principal document covering the management of inland, transitional and coastal waters in the EU. The current approach to its implementation regarding ecological assessment using biological elements is to develop assessment systems tailored to detect a response to a specific pressure. Although the WFD does not specifically mention invasive alien species (IAS) discussion has commenced on how to incorporate them into ecological assessment owing to their ability to significantly alter the structure and functioning of aquatic ecosystems. A potential framework is presented whereby IAS are treated as both a pressure and as part of a biological element to be monitored. It is proposed that the densities and distribution of IAS in water bodies are matched to normative definitions for quality classes in the WFD by expert groups at EU level. This would allow a rapid and consistent assignment of ecological status on the basis of IAS abundance and distribution in a water body. Such assessment should deal with IAS separately from other pressures. This would allow a separate report of the ecological degradation resulting from IAS so that specific management measures may be designed.

Key words: invasive alien species, Water Framework Directive, ecological assessment

Introduction

After habitat loss, invasive alien species (IAS) are considered the most important threat to biodiversity (IUCN 2000) while for some aquatic ecosystems such as lakes they are the principal threat because of frequent intentional introductions (Sala et al. 2000). The current framework policy document for the management of inland, transitional and coastal waters in the EU is the Water Framework Directive (WFD, European Community 2000). It requires an ecological assessment to be carried out on several biological elements: phytoplankton, benthic invertebrates, fish, phytobenthos and macrophytes (macroalgae and angiosperms in coastal and transitional waters) (Annex 5, European Community 2000).

The current approach being taken to implementation of ecological assessment under the WFD is to develop assessment systems based on a biological element tailored to detect a response to a specific pressure (Free et al. 2006; Solheim and Gulati 2008; Tóth et al. 2008). The change in species composition and abundance with departure from reference state along a pressure gradient is then divided into one of five ecological quality classes (high, good, moderate, poor or bad) in line with the narrative descriptions provided for each class in Annex 5 of the WFD. An intercalibration between EU states is then carried out so that the different methods and metrics used by states result in comparable assignment of status classes for water body types.

The WFD includes several parameters of relevance for pressures such as eutrophication, acidification, hydromorphological modification and dangerous substances. In addition, much research has taken place in the EU in developing ecological assessment systems to assess the extent of such pressures (e.g. Sixth Framework Programme funded project REBECCA: http://www.environment.fi/syke/rebecca).

However, IAS are not mentioned specifically in the WFD. Although, in the context of the directive’s objectives IAS represent an important pressure since they can modify the native biological structure and ecological functioning of aquatic systems. The assessment of IAS as a biological pressure should therefore be considered as part of a catchment management policy together with other pressures and should receive particular focus when assessing whether a water body is characteristic of reference status (REFCOND 2003; IMPRESS 2003). Some EU member states have acknowledged this to be the case. In their reports submitted to fulfil Article 5 of the WFD, which requires a review of the impact of human activity on the status of waters, they have included an assessment of alien species as a pressure at river basin district level (e.g. Anonymous 2005; several other Article 5 reports are available via http://circa.europa.eu/Public/irc/env/wfd/library).

Currently attention is focusing on how to incorporate IAS into the implementation of ecological assessment procedures as their presence can lead to ecological degradation, and should thus result in a lower classification of a water body. In addition, IAS are likely to confound the interpretation of some existing ecological assessment metrics. For example, Lough Key in Ireland has an area of 9 km^2 with a population of 10 billion *Dreissena polymorpha* (Pallas,1771) which have been estimated to filter the entire lake every 10 days (Lucy et al. 2005). Failure to account for this during an ecological assessment based on phytoplankton abundance would obviously lead to an erroneous view that the lake was not responding to nutrient pressure.

Since IAS are not directly mentioned in the WFD and given their unique position being both a biological pressure as well as a component of a biological element, a different approach than followed for other 'traditional' pressures may be justified. The purpose of this paper is to contribute to the discussion on how to incorporate IAS into ecological assessment in a pragmatic way in the context of WFD policy. Additional discussion and agreement is certainly needed so that a standardised EU approach is followed. This work was initially presented at a workshop on alien species and the EC Water Framework Directive, 2-3 April 2008, in Bordeaux, France.

Establishing a framework for incorporation of IAS into the WFD

Some of the desirable characteristics of a framework for incorporating IAS into ecological assessment under the WFD include:

- A metric or system should enable the combined pressure from all IAS in a water body to be expressed in an integrated way for each biological element.
- Many assessment systems currently in use are designed to respond to pressures that traditionally have received focus such as eutrophication and acidification (e.g. Kelly and Whitton 1995; Free et al. 2006; Schartau et al. 2008) and are unlikely to be good indicators of pressure from IAS. Ideally an IAS metric should be constructed as to be interpretable both as a response and as a pressure, placing IAS in the context of the (relevant) biological quality elements. Meaning, for example, that a high abundance of IAS simultaneously indicates high pressure and poor or bad ecological status.
- The assessment system should be separated into the five WFD quality classes and matched with the definitions of those status classes in Annex 5 of the Directive and associated guidance documents (i.e. guidance document 13, Working Group 2A 2005).
- Agreement should be reached on what levels of abundance/distribution of IAS in water bodies are likely to result in ecological degradation equivalent to the WFD status classes. Olenin et al. (2007) and Arbačiauskas et al. (2008) provide some examples of this.
- A system or metric should deal with IAS separate from other pressures. This would allow a separate report of the ecological degradation resulting from IAS so that specific management measures may be designed. It would also allow progress achieved from a program of measures aimed at reducing other pressures not to be obscured.

Suggested framework for incorporating IAS into ecological assessment:

1) Define list of IAS of relevance for each type of water body. This list should include all species that pose a risk of degradation in a water body from a high ecological status as measured by any of the WFD quality elements directly or indirectly. This may be compiled from national information or from information gathered by pan-European projects such as the Framework Programme 6 project DAISIE (Delivering Alien Invasive

Species Inventories for Europe: http://www.europe-aliens.org/).

2) For each IAS, field data is gathered on distribution and abundance. This may be gathered as part of routine monitoring programs or dedicated surveys as appropriate.
3) For each IAS an *a priori* assessment of the potential alteration of the ecological structure and functioning is carried out in the context of the normative definitions for each biological quality element in Annex 5 of the WFD (on a water body type-specific basis as mandated). This can be carried out using information from literature, observations at other sites or information on invasiveness. Specifically the abundance or distribution of the IAS is matched with status class expected as a result of the influence of the IAS alone. Ideally this would be done at EU level to ensure consistency of approach.
4) Where several IAS are present in a water body, the cumulative and or interactive influence of all IAS present should be assessed in the context of the normative definitions for each, or the most sensitive, biological element.

For each biological element the pressure from IAS is reported as one of the five WFD classes: high, good, moderate, poor and bad. This means that the metric may be interpreted as a pressure gradient or as a metric relating to a biological quality element in the ecological status classification. The latter has the benefit that it could be used alongside the other biological elements in the 'one out all out rule' where status is assigned based on the lowest score of the biological elements which could allow a lower ecological quality class to be assigned on the basis of IAS alone.

A worked semi-hypothetical example

Lake Monate, province of Varese in Northern Italy, has been reported to have low concentrations of chlorophyll a (4 µg l^{-1}) and TP (8 µg l^{-1}) and high > 5 m transparency (Tartari et al. 2005). Following a biological assessment the lake may be found to have low phytoplankton biomass, a deep depth of colonization by macrophytes and a normal profundal macroinvertebrate community with few taxa found that are indicative of eutrophic conditions. The overall assessment for the lake could be reported as good ecological status. An assessment is then made of the pressure likely to result from IAS following the steps above:

A list of IAS is constructed at national or EU level.

The routine monitoring data is supplemented with some specific monitoring for IAS. Three IAS are found in lake Monate: the crayfish *Procambarus clarkii* (Girard, 1852) (3 ind.m^{-2}) and *Orconectes limosus* (Rafinesque,1817) (3ind.m^{-2}) and the macrophyte *Lagarosiphon major* ((Ridley) Moss) (>82% of submerged and floating species; Tartari et al. 2005).

For each IAS an *a priori* assessment of the potential alteration of the ecological structure and functioning is carried out in the context of the normative definitions for each biological element in Annex 5 of the WFD. Specifically the abundance of the IAS is matched with status classes expected as a result of the influence of the IAS alone (for the sensitive biological elements). For example, experimental work on *Procambarus clarkii* has indicated that it can strongly affect communities of macroinvertebrates and macrophytes even at low densities of 4 ind. m^{-2} (Gherardi and Acquistapace 2007). This density could be aligned with the normative definitions in Annex 5 of the WFD for macroinvertebrates in lakes at moderate status: where "Major taxonomic groups of the type-specific community are absent". *Orconectes limosus* was also found at similar densities and would also likely represent a pressure capable of altering the macroinvertebrate community to moderate status (Pilotto et al. 2008). In addition the macrophyte *Lagarosiphon major* was found to comprise >82% of the submerged and floating species present which would represent a 'major alteration' from their type specific values corresponding to a reduction in quality to poor status (Table 1).

For classification of status, the approach to be followed would be to assign the lowest class found across the biological elements resulting from all pressures, including IAS pressure. This would be 'poor status' resulting from the dominance of *L. major* over the macrophyte community.

However, the IAS of crayfish are also likely to affect macrophyte communities in the lake owing to their omnivorous nature and this should be examined together with the dominance of *L. major* to decide whether a lower class should be awarded.

Table 1. Normative *general* definitions of ecological status classifications taken from Annex 5 of the WFD. Abundances of three IAS in lakes are tentatively matched with normative definitions for status classes for the example of lake Monate. Crayfish densities are in individuals per square metre of lake littoral. The occurrence of the macrophyte *Largarosiphon major* is expressed as percentage relative frequency, calculated as the number of sites at which it was present divided by the total number of sites sampled with submerged and floating macrophytes present. Only figures for the biological elements most sensitive to each IAS are presented.

Status class	General definitions of ecological quality for classes	e.g. of IAS matched with status class		
		O. limosus, ind m^{-2}	*P. clarkii,* ind m^{-2}	*L. major,* %
	Sensitive element:	invertebrates	invertebrates	macrophytes
High	There are no, or only very minor, anthropogenic alterations to the values of the physico-chemical and hydromorphological quality elements for the surface water body type from those normally associated with that type under undisturbed conditions. The values of the biological quality elements for the surface water body reflect those normally associated with that type under undisturbed conditions, and show no, or only very minor, evidence of distortion. These are the type-specific conditions and communities	0.0	0.0	<2
Good	The values of the biological quality elements for the surface water body type show low levels of distortion resulting from human activity, but deviate only slightly from those normally associated with the surface water body type under undisturbed conditions.	0.0-0.5	0.0-0.5	2-15
Moderate	The values of the biological quality elements for the surface water body type deviate moderately from those normally associated with the surface water body type under undisturbed conditions. The values show moderate signs of distortion resulting from human activity and are significantly more disturbed than under conditions of good status.	0.5-5.0	0.5-5.0	15-40
Poor	Waters showing evidence of major alterations to the values of the biological quality elements for the surface water body type and in which the relevant biological communities deviate substantially from those normally associated with the surface water body type under undisturbed conditions, shall be classified as poor.	5.0-10.0	5.0-10.0	40-90
Bad	Waters showing evidence of severe alterations to the values of the biological quality elements for the surface water body type and in which large portions of the relevant biological communities normally associated with the surface water body type under undisturbed conditions are absent, shall be classified as bad.	>10.0	>10.0	>90

Discussion

The key features of the proposed approach are that it recommends that lists of aquatic IAS are produced and that for each IAS an assessment of the potential alteration of the ecological structure and functioning is carried out in the context of the normative definitions for each biological quality element in Annex 5 of the WFD (on a water type-specific basis as necessary). Assessment of IAS pressure is therefore scaled in a similar way to an ecological quality ratio across five quality classes. This would essentially allow IAS to be treated as a pressure or in a similar way to a metric representing a biological element which would allow the use of the 'one out all out rule' that would potentially allow an ecological quality class to be assigned on the basis of IAS alone. This would be useful alongside a set of biological assessment metrics aimed at detecting other pressures such as eutrophication especially if IAS are not specifically included in those metrics or if they are treated as benign. It is, however, important not to average metrics designed to assess different pressures, the lowest value of a particular metric should be used, as averaging may conceal environmental degradation resulting from a particular pressure (Working Group 2A 2005).

The proposed system does not follow that being developed for WFD implementation for other pressures. However, to do so would require an enormous effort: establishing metrics for each biological element that are responsive to diverse types of IAS pressure and then intercalibrating such metrics across the EU. Following this approach would also lead to some circularity, for example, using the relative abundance of an IAS as a pressure while using the relative abundance of native taxa as a response. In contrast, one side benefit of agreeing densities or distribution of IAS that are equivalent to status classes would be that it promotes consistency of classification across the EU – as required by the WFD inter-calibration exercise (Nõges et al. 2005).

Whether non-native taxa will become invasive or not and whether they will drive species loss is hard to predict (Gherardi 2007a). Therefore in many cases it may prove difficult to establish generalised responses to given densities of alien species suitable for all examples of a water body type. However, for certain IAS consensus can often be achieved on those species which are associated most with ecological damage as seen by the production of 'most unwanted' lists (Evans 2006; DAISIE 2008). Nonetheless, it will be possible through examination of data collected by WFD required monitoring to validate that the *a priori* estimation of alteration by IAS is actually resulting in changes in a biological element that match its predicted status class. A long-term goal following successive rounds of monitoring of EU waters must be to produce integrated models of occurrence and impacts on aquatic ecosystems for non-native species. Such models are likely to be initially crude but nevertheless useful in management (Gherardi 2007b).

One added benefit of assessing IAS separately as advocated here is that it allows a separation of management strategies. Often the pressure exerted by IAS occurs alongside other anthropogenic pressures and joining them together in assessment systems may obscure progress in reducing the influence of one pressure such as nutrient export for example. Analysing pressures separately promotes transparency and allows for a clearer focus on the main pressures affecting a water body.

While the abundance of one alien species often has a dominating influence on the ecological quality of a water body this is not always the case. Instances where alien species introductions result in the addition of new functional groups into an ecosystem are of key importance as well as the overall abundance of alien species (Olenin et al. 2007). Similarly, the diversity of groups of alien species present may also have a significant influence on ecological status. Arbačiauskas et al. (2008) found that the proportion of identified orders comprised of alien species had a stronger negative influence on ecological quality than the relative abundance of alien specimens. Therefore, more research needs to be carried out on how to deal with and integrate the overall effect when there are several IAS present for each biological element as well as for the overall structure and functioning of the water body. Additional work could also focus on developing a similar approach for assessing the alteration of hydro-morphological and physico-chemical conditions by IAS in the context of the normative definitions in Annex 5 of the WFD.

In addition, the production of lists of IAS at EU level together with the expected resulting degradation in status class would serve to galvanise the focus of water authorities to increase awareness, prevention and early eradication of IAS. Ecological assessment of IAS should fit into an overall management framework including risk assessment and effective responses. One suitable framework may include the DPSIR model where assessment and actions are structured according to Driving forces, Pressures, State, Impact and Responses (Panov et al. 2009).

We have presented one possible way to incorporate IAS into ecological assessment in a pragmatic way within the policy framework of the WFD. Ultimately the approach to include IAS into WFD ecological assessment will be agreed by a group of national experts representing EU states. The political impetus comes from not just the WFD but also from the EU commitment to conserve biodiversity, which is greatly threatened by alien species (European Community 2006).

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References

Anonymous (2005) The characterisation and analysis of Ireland's river basin districts in accordance with section 7(2 and 3) of the European Communities (Water Policy) regulations 2003 (SI 722 of 2003) national summary report (Ireland) 2005. Available via http://www.wfdireland.ie

Arbačiauskas K, Semenchenko V, Grabowski M, Leuven RSEW, Paunović M, Son MO, Csányi B, Gumuliauskaitė S, Konopacka A, Nehring S, van der Velde G, Vezhnovetz V, Panov VE (2008) Assessment of bio-contamination of benthic macroinvertebrate communities in European inland waterways. *Aquatic Invasions* 3: 211–230, http://dx.doi.org/10.3391/ai.2008. 3.2.12

DAISIE: Delivering Alien Invasive Species Inventories for Europe (2008) 100 of the Worst. Available via http://www.europe-aliens.org/speciesTheWorst.do

European Community (2000) Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. *Official Journal of the European Communities* L327: 1-72

European Community (2006) Halting the loss of biodiversity by 2010 – and beyond. Sustaining ecosystem services for human well-being. COM (2006) 216

Evans H (2006) Top ten most unwanted foreign species. Document reference: TC164/06IJ. Available via http://www.environment-agency.gov.uk

Free G, Little R, Tierney D, Donnelly K, Caroni R (2006) A reference based typology and ecological assessment system for Irish lakes. Preliminary investigations. Environmental Protection Agency, Wexford. Available via http://www.epa.ie

Gherardi F (2007a) Biological invasions in inland waters: an overview. In: Gherardi F (ed), Biological invaders in inland waters: Profiles, distribution, and threats. Springer, Dordrecht, pp 3-25, http://dx.doi.org/10.1007/978-1-4020-6029-8_1

Gherardi F (2007b) Measuring the impact of freshwater NIS: what are we missing? In: Gherardi F (ed), Biological invaders in inland waters: Profiles, distribution, and threats. Springer, Dordrecht, pp 437-462, http://dx.doi.org/10.1007/978-1-4020-6029-8_24

Gherardi F, Acquistapace P (2007) Invasive crayfish in Europe: the impact of *Procambarus clarkii* on the littoral community of a Mediterranean lake. *Freshwater Biology* 52: 1249-1259, http://dx.doi.org/10.1111/j.1365-2427.2007.01760.x

IMPRESS (2003) Common implementation strategy for the Water Framework Directive (2000/60/EC), guidance document 3, analysis of pressures and impacts. Office for Official Publications of the European Communities, Luxembourg. Available via http://circa.europa.eu/Public/irc/env/wfd/library

IUCN (2000) IUCN guidelines for the prevention of biodiversity loss caused by alien invasive species. Approved by the 51st Meeting of the IUCN Council, Gland, Switzerland, February 2000. Available via http://www.iucn.org/themes/ssc/publications/policy/invasivesEng.htm

Kelly MG, Whitton BA (1995) The trophic diatom index: a new index for monitoring eutrophication in rivers. *Journal of Applied Phycology* 7: 433-444, http://dx.doi.org/10.1007/BF00003802

Lucy F, Sullivan M, Minchin D (2005) Nutrient levels and the zebra mussel population in Lough Key. Environmental Protection Agency, Wexford. Available via http://www.epa.ie

Nõges P, Van de Bund W, Cardoso AC, Heiskanen A-S (2005) Setting ecological quality class boundaries for the Water Framework Directive: the lake intercalibration network. *Verhandlungen der Internationale Vereinigung für Theoretische und Angewandte Limnologie* 29: 265-267

Olenin S, Minchin D, Daunys D (2007) Assessment of biopollution in aquatic ecosystems. *Marine Pollution Bulletin* 55: 379-394, http://dx.doi.org/10.1016/j.marpolbul.2007.01.010

Panov VE, Alexandrov B, Arbačiauskas K, Binimelis R, Copp GH, Grabowski M, Lucy F, Leuven RSEW, Nehring S, Paunović M, Semenchenko V, Son MO (2009) Assessing the risks of aquatic species invasions via European inland waterways: from concepts to environmental indicators. *Integrated Environmental Assessment and Management* 5: 110-126

Pilotto F, Free G, Crosa G, Sena F, Ghiani M, Cardoso AC (2008) The invasive crayfish Orconectes limosus in Lake Varese: estimating abundance and population size structure in the context of habitat and methodological constraints. *Journal of Crustacean Biology* 28: 637-644, http://dx.doi.org/10.1651/07-2967.1

REFCOND (2003) Common implementation strategy for the Water Framework Directive (2000/60/EC), guidance document 10, river and lakes – typology, reference conditions and classification systems. Office for Official Publications of the European Communities, Luxembourg. Available via http://circa.europa.eu/Public/irc/env/wfd/library

Sala OE, Chapin FS, Armesto JJ, Berlow E, Bloomfield J, Dirzo R, Huber-Sanwald E, Huenneke LF, Jackson RB, Kinzig A, Leemans R, Lodge DM, Mooney HA, Oesterheld M, LeRoy Poff N, Sykes MT, Walker BH, Walker M, Wall DH (2000) Global Biodiversity Scenarios for the Year 2100. *Science* 287: 1770-1774, http://dx.doi.org/10.1126/science.287.5459.1770

Schartau AK, Moe SJ, Sandin L, McFarland B, Raddum GG (2008) Macroinvertebrate indicators of lake acidification: analyses of monitoring data from UK, Norway and Sweden. *Aquatic Ecology* 42: 293-305, http://dx.doi.org/10.1007/s10452-008-9186-7

Solheim AL, Gulati RD (2008) Preface: 'Quantitative ecological responses for the Water Framework Directive related to eutrophication and acidification of European lakes'. *Aquatic Ecology* 42: 179-181, http://dx.doi.org/10.1007/s10452-008-9187-6

Tartari G, Monguzzi C, Buraschi E, Di Pasquale D, Cattaneo O, Lucchelli M, Rossi S, Bartesaghi G, Paleari M, Bolis B, Magni D (2005) Osservatorio dei Laghi Lombardi. Qualità delle acque lacustri in Lombardia. 1° Rapporto OLL – 2004. Fondazione Lombardia per l'Ambiente

Tóth LG, Poikane S, Penning WE, Free G, Mäemets H, Kolada A, Hanganu J (2008) First steps in the Central-Baltic intercalibration exercise on lake macrophytes: where do we start? *Aquatic Ecology* 42: 265-275, http://dx.doi.org/10.1007/s10452-008-9184-9

Working Group 2A (2005) Common implementation strategy for the Water Framework Directive (2000/60/EC), guidance document 13, overall approach to the classification of ecological status and ecological potential. Office for Official Publications of the European Communities, Luxembourg. Available via http://circa.europa.eu/Public/irc/env/wfd/library