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SCIENTIFIC OPINION

Scientific Opinion on the environmental risk assessment of the apple snail for the EU[1]

EFSA Panel on Plant Health (PLH)[2,3]

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ABSTRACT

At EFSA's request, the Plant Health Panel (PLH) performed an environmental risk assessment (ERA) of the apple snail for the EU and validated the ERA approach presented in the PLH ERA guidance document. Improvements and suggestions for simplification of the ERA are provided. One service-providing unit—shallow fresh water areas—was identified for this ERA. The effects of resistance, resilience and management on snail population dynamics in the short (5 years) and the long term (30 years) were estimated. In line with the PLH ERA guidance rating system, expert judgement was used to evaluate separately the impacts on (i) ecosystem traits, (ii) ecosystem services and (iii) biodiversity components. Snail biomass values were predicted to be higher in the short term than in the long term. For ecosystem services, moderate risk was estimated for genetic resources, climate regulation, pest and disease regulation and pollination in both the short and long term; for food, risk was assessed as moderate in the short term and major in the long term; for water and erosion regulation, risk was assessed as major both in the short term and in the long term; for fresh water, risk was assessed as massive both in the short term and in the long term; and for nutrient cycling and photosynthesis and primary production of macrophytes, risk was assessed as massive in the short term and as major in the long term. For biodiversity components, risk for genetic diversity and native species diversity was estimated as major in both the short and the long term; risk for native habitats was assessed massive in the short term and major in the long term; and for threatened species and habitats of high conservation value, risk was determined as massive in both the short and the long term.

KEY WORDS

apple snail, *Pomacea* spp., environmental risk assessment, scenario analysis, ecosystem traits, ecosystem services, biodiversity components

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SUMMARY

The European Food Safety Authority (EFSA) asked the Plant Health Panel (hereinafter referred to as the Panel) to deliver a scientific opinion on the risk the apple snail poses to the environment of the European Union (EU). The Panel was requested to review the current state of the art of the biology and ecology of apple snails of the genus *Pomacea*, and to perform an environmental risk assessment (ERA) using the invasive species of *Pomacea* as a case study for validating the Panel's guidance document on ERA (EFSA PLH Panel, 2011), hereinafter referred to as PLH ERA guidance. This was also deemed necessary since the Spanish pest risk analysis (Spanish Ministry of Environment and Rural and Marine Affairs, 2011) did not sufficiently address the environmental impacts of the apple snail (EFSA PLH Panel, 2012a).

In this scientific opinion, when the Panel refers to the apple snail, it refers specifically to *Pomacea maculata* and to *P. canaliculata.* As these species are closely related, their population dynamics pattern and potential impacts are assumed by the Panel to be similar.

In this document, the Panel presents the ERA of the apple snail for the EU territory, including an analysis and evaluation of the risk assessment methodology applied to the apple snail. In EFSA PLH Panel (2013), the Panel reviewed the current state of the art of the biology and ecology of the apple snail and used a population dynamics model to assess its establishment in terms of density distribution in Europe. The Panel used these results as a starting point for performing the ERA.

Conclusions concerning the methodological approach and its simplification

The PLH ERA guidance includes a detailed procedure with different consecutive steps to assess the impacts of plant pests on ecosystem traits, ecosystem services and biodiversity components. In the current opinion, when performing the assessment, the complete PLH ERA approach was tested to evaluate the different steps described in the ERA guidance. Some aspects of the guidance were modified to improve it, and suggestions were made to simplify the approach and to make it more flexible.

In this opinion, the results obtained by the population dynamics model developed for *P. canaliculata* (EFSA PLH Panel, 2013) are summarised to describe the potential establishment and population density of the apple snail in different areas of Europe. However, in the current opinion, the Panel assessed snail population densities not in terms of number of eggs, juveniles and adults, but instead using a snail biomass index to represent density, which combines the fresh weights of the snail stages and supports the evaluations of the impacts on ecosystem services and biodiversity.

Definition of the service-providing unit

In the *Pomacea* case study, only one service-providing unit (SPU) was identified, i.e. shallow fresh water areas containing macrophytes, such as wetlands, shallow lakes, river deltas and the littoral zone of deeper lakes and rivers, which simplified and shortened the assessment, consequently decreasing its complexity.

Temporal, spatial and biomass scales and the influence of resistance, resilience and management

In this assessment, only the area of potential establishment as predicted by the population dynamics model was taken into account. The influence and the time variability of resistance, resilience and management led to the consideration of two different scenarios for this case, a short-term assessment 5 years after establishment (main influence: resistance of the ecosystem) and a long-term assessment 30 years after establishment (main influence: resilience).

Rating system

The rating system described in the PLH ERA guidance document appeared easily applicable and transparent. Experts were asked to estimate the magnitude of impacts by assigning a percentage to the expected reduction in each ecosystem service or a biodiversity component of between 0 and 100 %. Uncertainty was addressed by considering the distribution of the expected impact over the categories

between 1 and 5 (minimal to massive). Experts first individually provided their ratings including the uncertainties, then discussed their ratings and agreed on final ratings. This procedure improved the accuracy of the ratings and reduced the uncertainty in some cases.

Changes made in the ERA approach applied for the Pomacea case

Creating traits–ecosystem services clusters as described in the PLH ERA guidance was found to be very complex. Therefore, the impacts on ecosystem traits, ecosystem services and biodiversity were assessed in a direct, separate evaluation using expert judgement. This procedure also reduced uncertainty, because at least some scientific evidence could be provided. To homogenise and simplify the approach, impacts on biodiversity and ecosystem services were assessed and rated in the same way. Since the ERA is based on a scenario analysis, an assessment of the area of origin is not considered logical, because scenarios are based on the biomass that is predicted for the risk assessment area by the population dynamics model and the impacts that are expected.

Simplification of ERA

The Panel does not propose to perform a detailed ERA in all cases. Therefore, before starting an ERA, it is essential to define the level at which the assessment should or needs to be conducted. Suggestions for different ways to implement the ERA are presented in the Section ‘Recommendations’.

Conclusions concerning environmental risks posed by *Pomacea*

According to the population dynamics model (EFSA PLH Panel, 2013) the area of potential establishment of *Pomacea* comprises wetlands of southern Europe (i.e. Spain, southern France, most of Italy and Greece) and the Balkans up to the latitude of the Danube River.

High potential biomass values (more than 20 g/m^2 in snail fresh weight) are predicted for a large number of coastal and inland Mediterranean locations, but realised biomass values were smaller (84 % of the potential biomass at the 5 years time horizon and 40 % of the potential biomass at the 30 years time horizon) after application of the scaling factors (resistance, resilience and management). The average realised snail biomass after 30 years is lower than after 5 years, because it is expected that (i) macrophytes that are non-palatable to *Pomacea* will replace palatable macrophytes, which will largely disappear, and (ii) natural enemies may reduce the apple snail density more efficiently at the longer time horizon.

The Panel assessed the effect of snail biomass on a number of ecosystem traits and assessed the impact of snail invasion on the ecosystem services in the worst-case scenario. In the context of the current ERA, considering that the driving force of the ecosystem change is apple snail biomass, some services are not expected to be modified, and only a selection of the provisioning services and regulating–supporting services have been retained for evaluation. The Panel also assessed the impact of snail invasion on biodiversity in the worst-case scenario, for both structural and conservation components. In order to systematically assess the impact of snail invasion on the ecosystem services and biodiversity components, a number of traits–services clusters and traits–biodiversity components clusters have been schematised by the Panel. For each ecosystem service and biodiversity component, the risk was calculated in both the short and the long term.

With regard to the ecosystem services, the Panel concludes that the presence of the apple snail results in a moderate risk for genetic resources, climate regulation, pest and disease regulation and pollination in both the short and the long term. The risk for food is moderate in the short term and major in the long term. The risk for water regulation and erosion regulation is major in both the short and the long term. The risk for fresh water is massive in both the short and the long term. The risk for nutrient cycling and photosynthesis and primary production of macrophytes is massive in the short term and major in the long term. In the worst case scenario, the overall effect of the snail invasion on the shallow freshwater wetlands of southern Europe is major on the ecosystem services both in the short and in the long term.

For the biodiversity component, the Panel concludes that the presence of the apple snail results in a major risk for genetic diversity and native species diversity in both the short and the long term. For native habitat, the risk is massive in the short term and major in the long term. For threatened species and habitat of high conservation value, the risk is massive in both the short and the long term. In the worst case scenario, the overall effect of the snail invasion on the shallow freshwater wetlands of southern Europe is massive on the biodiversity in the short term and major in the long term.

In future work, the methodology used in this opinion to produce the maps of the spatial distribution of impact on some ecosystem traits, ecosystem services and biodiversity components could also be compared with maps of special wetland areas under Natura 2000 (Council Directive 92/43 EEC[4]). The objective of this comparison would be to visualise the relevant habitats present in the assessment area that are potentially affected by the presence of the apple snail. However, to do this in a scientifically sound way, it would be necessary to relate these maps more clearly to the quantitative analysis of the impacts on ecosystem traits, ecosystem services and the biodiversity components of those habitats considered in the ERA.

Recommendations

The Panel recommends the following:

1. Consider the use of a population dynamics model to estimate both establishment and population density of emerging pests in the risk assessment area.
2. Use the population density to assess the impact of pests on ecosystem services and biodiversity.
3. Do not consider the area of origin of the pest, but focus the assessment on the risk assessment area, in accordance with the scenario(s) being developed for the risk assessment area.
4. Evaluate ecosystem traits, biodiversity components and ecosystem services directly without quantifying the interactions represented in the traits–services and traits–biodiversity clusters.
5. Assess impacts on ecosystem services and biodiversity in the same way.
6. Define the level at which an ERA needs to be conducted before starting the assessment by considering the following questions:
    (a) How much and which relevant knowledge is available?
    (b) What are the objectives of the risk assessor(s) for the ERA and on which level do they have to be addressed?
    (c) Which resources are available to perform the ERA?
7. Consider a number of simplifications related to the description and selection of assumptions, the selection and the amount of detail to describe traits and ecosystem services, and the assessment of the impacts on ecosystem services and biodiversity.
8. Set out the whole revised ERA procedure in a flow chart to obtain a clear overview of the various steps and different possibilities, including a decision support scheme.
9. Discuss the new PLH ERA approach with other organisations involved in ERA, or present it to them, with the aim of complementing other risk assessments and harmonising where possible and needed.
10. Consider how the innovative method used to perform the ERA might influence other elements of a pest risk assessment.

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[4] Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. OJ L 206, 22.7.1992, p. 7–50.

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BACKGROUND AS PROVIDED BY EFSA

The Scientific Panel on Plant Health (PLH Panel) provides independent scientific advice on the risks posed by organisms which can cause harm to plants, plant products or plant biodiversity in the European Community. The Panel reviews and assesses those risks with regard to the safety and security of the food chain to assist risk managers in taking effective and timely decisions on protective measures against the introduction and spread of harmful organisms in the European Community. On request, the Panel prepares pest risk assessments and identifies and evaluates the effectiveness of risk reduction options to provide scientific advice to the European Commission in support of protective measures within the European Community to prevent the introduction and further spread of organisms considered harmful to plants or plants products under the Council Directive 2000/29/EC[5].

In 2011 the PLH Panel evaluated a Spanish Pest Risk Analysis (EFSA PLH Panel, 2012a), and recommended that further study should be performed on the potential consequences of the *Pomacea* genus for the European environment. The assessment of environmental consequences of the *Pomacea* spp.-induced transformation of wetland ecosystems presented in the Spanish Pest Risk Analysis demonstrates some limits in the capacity to predict the interaction of the snails and the receiving communities and ecosystems. These limits affect the possibility of extrapolating the findings in Asia to the EU territory. Given that projections of environmental consequences are based on a scenario exercise, a more structured and ecologically sound approach would strongly contribute to providing insight into the future development of the snail invasion and its consequences. In particular, the following aspects might be considered for the development of an environmental risk assessment for the *Pomacea* snails in the EU territory:

(i) The snail population density. The environmental consequences of snail invasion have been proven to be dependent on the snail population density. It appears to be essential to project not only the potential area of invasion, based on simple climate matching, but also to produce a scenario of potential impact based on adequate consideration of the snail's biology and its ecology at the basis of population dynamics. The development of a snail population dynamics model may assist the computation of the potential population density over all the suitable areas in continental Europe. This model should include temperature-dependent responses of development, survival and reproduction. The role of host availability and density can also be taken into account in model projections, if data are available.

(ii) Development of scenarios of potential consequences. To develop a scenario of potential consequences the following information is required: (a) projection of the potential population density; (b) hypothesis on pest spread potential; (c) information on the distribution of the potentially affected habitats including habitats other than rice fields and natural wetlands that may be invaded by the pest such as rivers, shallow lakes and ponds (these ecosystems are also likely to be affected by the *Pomacea* snails and may serve as reservoirs for the snails and as an infrastructure for spread). Such information can support the estimation of (1) the environmental consequences on natural wetlands and (2) the potential impact on rice fields.

(iii) Perform a structured evaluation based on biodiversity and ecosystem services. The published guidance on the environmental risk assessment of plant pests (EFSA PLH Panel, 2011) provides a structured methodological framework for assessing the environmental risks of plant pests and is very suitable for development of an environmental risk assessment for *Pomacea* snails in the risk assessment area. The guidance emphasises the importance of assessing the consequences on both the structural (biodiversity) and the functional (ecosystem services) aspects of the environment. This new approach includes methods for assessing the environmental effects on both aspects (structural and functional) for the first time in a pest risk

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[5] Council Directive 2000/29/EC on protective measures against the introduction into the Community of organisms harmful to plants or plant products and against their spread within the Community. OJ L 169, 10.7.2000, p. 1 – 112.

assessment scheme and is particularly suitable for a plant pest such as *Pomacea* spp., which represents an important driving force of wetland ecosystems change.

Furthermore in 2012, The PLH Panel has published a statement on the identity of the apple snails (EFSA PLH Panel, 2012b), and considered that the uncertainties on the invasive potential of the apple snail that are mainly related to the poor knowledge of the biology and ecology of most of the *Pomacea* species that does not allow grading of the invasive potential at species level. The understanding of the invasive potential is also limited by possible change in the invasiveness after establishment.

TERMS OF REFERENCE AS PROVIDED BY EFSA

In this context EFSA requests the PLH Panel to produce an environmental risk assessment of the apple snails for the EU territory. Specifically, the Panel is requested to:

- Review the current state of the art of the biology and ecology of the apple snails;
- Perform an environmental risk assessment using the invasive species of *Pomacea* as a case study for validation of the Plant Health environment guidance document (EFSA PLH Panel, 2011).

The Panel expects to deliver the scientific opinion by March 2014.

ASSESSMENT

1. Introduction

The island apple snail (previously called *Pomacea insularum* (d'Orbigny, 1835) and now called *P. maculata*) is one of the largest fresh water snails. *P. maculata*, along with other species belonging to the same genus, is highly invasive outside its native distribution range (South America), which might be the result of its polyphagy and high reproductive rate. The apple snail is considered to be a serious rice pest and can cause devastating effects on the flora and fauna of natural fresh water wetlands. In 2010, the organism invaded rice fields in the Ebro Delta in Spain. Before then, it was not known to occur in the European Union (EU) and was not regulated. Since November 2012, the invasive snail has been regulated in the EU by a Commission Implementing Decision[6]. Currently, apple snail invasion is continuing in the Ebro Delta despite control measures to eradicate and/or contain the snail in the rice paddies. Mechanical and chemical control measures are used, as well as inundation of paddies with saline water and other methods. At present, the snail is present not only in rice paddies, but also in some nearby wetlands, and it has been found moving upwards along the Ebro riverbeds.

At the request of the European Commission (EC) the Panel on Plant Health (hereinafter referred at as the Panel) provided advice in two different documents regarding the apple snail in 2012:

- EFSA PLH Panel, 2012a. Scientific Opinion on the evaluation of the pest risk analysis on *Pomacea insularum*, the island apple snail, prepared by the Spanish Ministry of Environment and Rural and Marine Affairs.

- EFSA PLH Panel, 2012b. Statement on the identity of apple snails.

In its evaluation, provided in the scientific opinion, the Panel concluded that the Spanish pest risk analysis (Spanish Ministry of Environment and Rural and Marine Affairs, 2011) did not sufficiently address the environmental impact of snail invasion and recommended that further study should be performed. The Panel was therefore requested by EFSA to perform an environmental risk assessment (hereinafter referred to as an ERA) on the apple snail following the guiding principles presented in the PLH guidance document (EFSA PLH Panel, 2011, hereinafter referred to as PLH ERA guidance document). While performing the ERA, the Panel was also asked to use this as a case study and evaluate and update the guidance document.

In EFSA PLH Panel (2013), the Panel presented the current state of the art of the biology of apple snails, and developed and used a population dynamics model to assess the potential establishment of apple snails in the EU in terms of the spatial distribution of the snail's population density.

In this scientific opinion the Panel uses the data on biology and ecology of the apple snail and the results of the population dynamics model, presented in EFSA PLH Panel (2013), to perform an ERA following the guiding principles detailed in the PLH ERA guidance document. This task has been performed considering the possible simplification and adjustments to the Panel's environmental risk assessment guidance document.

In this scientific opinion, when the Panel refers to the apple snail, it refers specifically to *Pomacea maculata* and to *P. canaliculata.* As these species are closely related, their population dynamics pattern and potential impacts are assumed by the Panel to be similar, under the assumptions detailed in EFSA PLH Panel (2013).

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[6] Commission Implementing Decision 2012/697/EU of 8 November 2012 as regards measures to prevent the introduction into and the spread within the Union of the genus *Pomacea* (Perry). OJ L 311, 10.11.2012, p. 14–17.

2. Methodology

2.1. The ERA *Pomacea* framework

The ERA of the apple snail has been performed following the principles described in the EFSA guidance on ERA of invasive species (EFSA PLH Panel, 2011).

In a nutshell the different concepts used to perform the ERA are:

- The invasive species is considered the driver of ecosystem change.
- The definition of impact relates to the specific service-providing unit (SPU).
- The impact depends on the resistance and resilience of the system.
- The impact also depends on the management of the invasive species.
- The impact is assessed under specific assumptions defining the scenarios of the assessment.
- Only the negative impacts of the apple snail on the traits, ecosystems services and biodiversity components are assessed.
- First the relationships between the driver of the ecosystem change (i.e. the snail biomass) and the ecosystem traits are assessed.
- Then the clusters traits–biodiversity and traits–ecosystem services are identified.
- Finally, the impact on the biodiversity and ecosystem services components is assessed considering the impact on traits previously evaluated.

The described procedure is summarised in Figure 1.

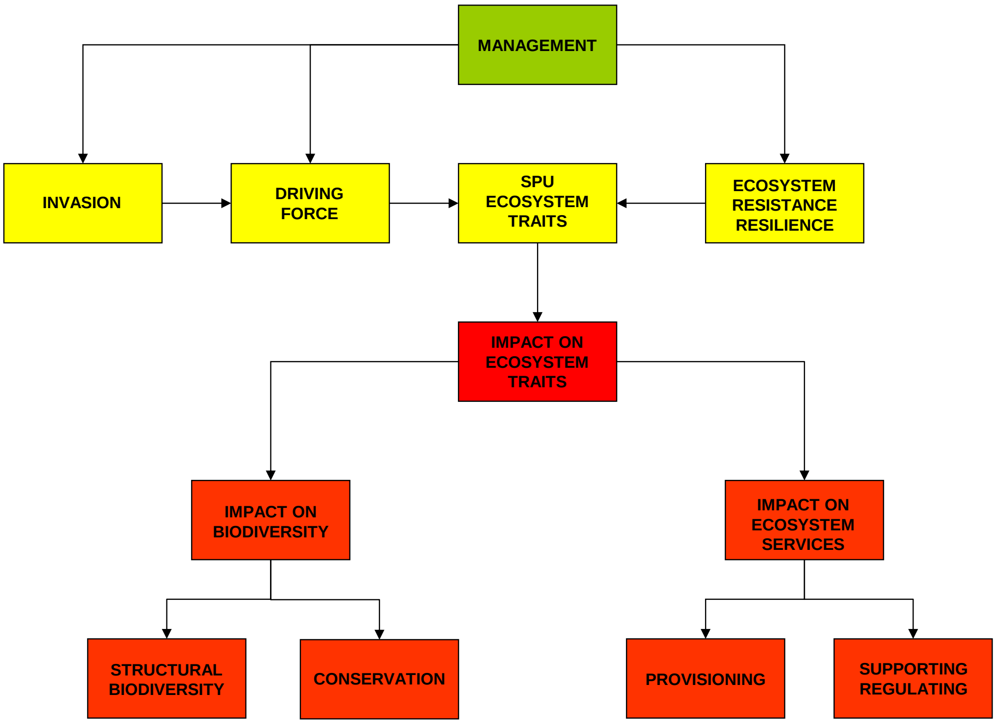


Figure 1: A scheme of the procedure for assessing the environmental risk posed by the apple snail. The scheme is derived from the one proposed in the PLH ERA guidance (EFSA PLH Panel, 2011).

While conducting the ERA for the apple snail, some changes to the original scheme as presented in the PLH ERA guidance in 2011 were introduced. The most important theoretical advancement is the introduction of the density dimension (in this opinion in the form of snail biomass) in the scenario analysis together with the spatial and the temporal dimension (see Section 2.2). A new approach has been developed to address the ERA of the apple snail. The approach is based on different procedures for collecting expert judgements related to different aspects of the assessment (impact on ecosystem traits and risks posed to ecosystem services and biodiversity components) (see Section 2.3).

The glossary provides explanations of the technical terminology used throughout this document.

2.2. The new scenario analysis and the density dimension

Knowing the population density of an invasive species and its spatial and temporal variation is essential to determine the spatial and temporal pattern of the environmental impact. The density is the most important state variable that the Panel uses to describe and predict the outcome of the trophic relationships between a pest and its host plants. The effect of this trophic interaction on the host plants community is the first element to be considered in order to understand the ecosystem disturbance produced by a plant pest.

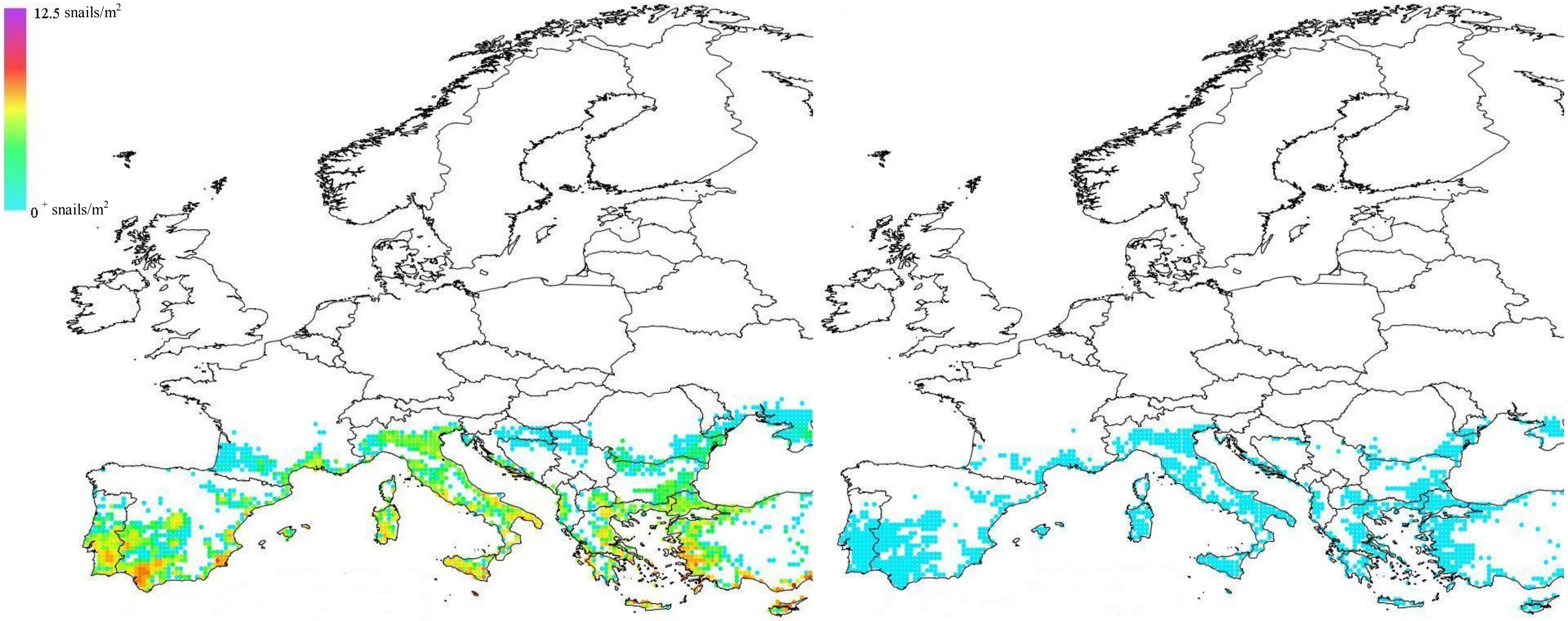
In this opinion, a method based on the information on the density distribution of snails is used to evaluate the potential environmental impact of the snail in the assessment area.

In EFSA PLH Panel (2013), to estimate the area of potential establishment of the apple snail in the EU, the Panel developed a population dynamics model for *Pomacea canaliculata*, a closely related species to *P. maculata*, identified as the invasive apple snail in the Ebro Delta in Spain.

P. canaliculata is also a worldwide invasive apple snail, and one for which more bio-ecological information is available. The Panel assumes that the species are similar in terms of their population dynamics pattern and potential impacts. Snail population dynamics depend on development, reproduction and mortality, which are strongly influenced by temperature. Density-dependent population regulation is included into the model to account for intraspecific competition. Additional mortality is introduced into the model as an averaged effect of the temperature-independent and density-dependent mortality. A 25 × 25 km simulation grid is considered to cover the whole of Europe. In each node of the grid the potential snail population abundance was calculated using a physiologically based demographic model (Metz and Diekmann, 1986; Curry and Feldman, 1987; Gutierrez, 1996; Di Cola et al., 1999). *P. canaliculata* is considered a stage-structured population comprising three stages: egg, juvenile and reproductive adult. Demographic processes are described by means of temperature-dependent biodemographic functions (development, mortality and fecundity for reproductive females). The functional forms of these functions are the same as used for many other poikilotherm species, and parameters were estimated using available literature data on *P. canaliculata* (Albrecht et al., 1999, 2005; Estebenet and Martin, 2002; Yingying et al., 2008; Burela and Martin, 2011; Y. Liu et al., 2011; J. Liu et al., 2012; Seuffert and Martín, 2012, 2013). Population dynamics were described by a Kolmogorov equation discretised with a time step of one hour for each point of the spatial grid (Di Cola et al., 1999). The simulated abundance in each node was obtained using the specific climatic condition of the node. The potential distribution of the apple snail *P. canaliculata* in Europe was obtained by calculating the average abundance per year for each node of the grid covering Europe. For further details on the model and data, see EFSA PLH Panel (2013).

In EFSA PLH Panel (2013), two cases were considered, which differed in the mortality rate function: one case was less favourable to apple snail establishment owing to higher mortality (PM2.0) and the other more favourable (PM1.5) owing to lower mortality. In the ERA presented in this scientific opinion, the Panel considers only the model with the lower mortality (PM1.5).

Figure 2 shows the predicted potential distribution and density (individuals per m^2) of *P. canaliculata* for juveniles (Figure 2a) and adults (Figure 2b).



a. juvenile snails **b. adult snails**

Figure 2: Potential distribution and density of *Pomacea canaliculata* in Europe obtained with the apple snail population dynamics model: (a) juveniles; (b) adults. The colour code in the legend corresponds to densities above 0 (individuals per m^2).

The area of potential establishment of the apple snail comprises part of southern Europe and includes the rice production areas and most of the wetlands of southern Europe and the Balkans up to the latitude of the Danube River. The northern limit of the potential distribution of snails in Europe is in the Po Valley (Italy). Coastal areas in the Mediterranean area are generally more suitable than inland areas. Adult population density is generally low (Figure 2b). Juvenile population density is generally higher than adult population density. Several hotspots (locations with an infestation of more than five juveniles per square metre) corresponding in the map of Figure 2a to the colour changes from light green to yellow.

Pest population density can be expressed in terms of numbers or biomass per unit area or volume. In the case of herbivores, biomass, if related to the information on the type of damage and the metabolic rates of the pest, can be even more informative than numbers to account for the population pressure on the environment. In the epidemiology of plant diseases, the prevalence of a disease in a given plant population per unit of area or volume can be considered the equivalent of the population density concept. The spatial distribution of the density, expressed in terms of apple snail biomass per unit area of suitable habitats, is derived from the population dynamics model developed in EFSA PLH Panel (2013).

2.3. The adaptation of the assessment scheme

The generic ERA scheme proposed in the PLH ERA guidance will usually need to be adapted to the specific requirements of an invasive organism, its host plants and its potential impact on the environment, as well as the objectives of the analysis, current knowledge and the resources available for the assessment. For the ERA of the apple snail, the following should be emphasised:

- The scientific principles of the ERA for invasive species and the procedure for constructing the scenarios given in the PLH ERA guidance were very useful to develop the options for the assessment of environmental risks posed by the apple snail.
- The evaluation of the impact on the ecosystem traits was performed and impacts could often be supported by scientific evidence.
- As expected, designing and quantifying the links between impact on ecosystem traits and on biodiversity components as well as on ecosystem services was a complex exercise.
- The experts involved in the assessment apparently used two different cognitive approaches for the assessment of the impact on the traits and on biodiversity and ecosystem services. For the traits the assessment was generally linked to knowledge on available data and interpretation of specific ecological dynamics in a system under perturbation. For biodiversity and ecosystem services, the level of analysis was mainly integrative and conceptual, and required incorporation of different sets of knowledge.

On the basis of the above-mentioned points:

- The Panel performed three types of assessment based on expert judgements at three different levels of detail: (i) estimation of values of the scaling factors limiting the potential biomass, (ii) estimation of the impacts on the ecosystem traits and (iii) estimation of the impacts on biodiversity and ecosystem services.
- The Panel developed three slightly different methods to collect expert judgements to address these three types of assessment.
- The Panel proceeded in three consecutive steps.
    - First, to complete the scenario analysis, the Panel asked the experts to estimate the values of the scaling factors (resistance, resilience and management) that reduce the potential biomass at two time horizons (short term, 5 years; and long term, 30 years) and to use the estimates to calculate the realised biomass (see i).

  - Second, the Panel assessed the impact on ecosystem traits in relation to the snail biomass (see ii). The consideration of the impact on different traits facilitates the evaluation of systemic effects due to the interactions between the traits.
  - In the third step, an assessment of the impact on the integrative levels of biodiversity and ecosystem services was carried out (iii).
- Finally, the assessments conducted at different levels were then checked by the same experts to consider any discrepancies or inconsistencies among assessments.

2.4. The collection of expert judgements

To obtain information about the impact of snails on ecosystem services and biodiversity, a panel of five experts with knowledge of the biology and ecology of the apple snail and of the ecology of wetlands was established.

2.4.1. Scaling factors

The biomass expected at the two time horizons (5 and 30 years) can then be obtained by multiplying the potential biomass in each node of the assessment area by the value in the node for the three scaling factors (resistance, resilience and management) at the different time horizons. Further details of the approach are provided in Section 3.4.

For each scaling factor, each individual expert gave an estimate of the mean value and an estimate of the range of variability around this mean value, intended as an interval in which the value of the scaling factor falls with 95 % probability. Next, a single 95 % confidence interval was obtained by combining the confidence intervals estimated by the experts (Appendix A). Then, mean values and confidence intervals were used to design maps of the realised biomass. Three types of maps were designed for the two time horizons: one map is based on the multiplication of the potential biomass by the mean values of the scaling factors and the other two maps are based on multiplication of the potential biomass by the lower and upper bounds of the scaling factors.

2.4.2. Impact on ecosystem traits

The impact on ecosystem traits was evaluated as a function of potential snail biomass. Experts were consulted to assess how the variation of the potential snail biomass affects a given trait of the ecosystem. The level of the variable measuring the state of each ecosystem trait is set equal to 1 for a potential snail biomass of 0 (no snails). In addition, the potential snail biomass was normalised to the highest value obtained for the assessment area, which was 31.5 g of snail per square metre of fresh weight.

During a consultation meeting, the experts involved in the procedure were asked to reach an agreement on the possible variation of the impact on each ecosystem trait separately. The impact is measured in terms of change in the level of the ecosystem trait due to the increase in snail biomass. Four levels of potential snail normalised biomass have been considered: 0.25, 0.5, 0.75 and 1. Then, the estimated changes in the four values of the trait were interpolated to obtain continuous functions for the relationship between potential snail biomass and impact on ecosystem traits (see Section 4.2).

The objectives for this assessment were twofold:

(i) to assess the value of the impact on the ecosystem traits at the two time horizons defined in the study;

(ii) to create high-resolution maps (25 × 25 km) of the spatial distribution of the impact on the ecosystem traits;

2.4.3. Impact on ecosystem service and biodiversity components

The impacts on the components of biodiversity and ecosystem services have been evaluated by using the method based on the probability distributions described in Appendix B. Experts were consulted through a questionnaire presented in Appendix B. Together with the questionnaire, guidelines for the assessment of the impact of snail invasion on ecosystem services and biodiversity components were provided. The guidelines present the information necessary to perform the assessment and include:

- a description of the method for the assessment;
- the assumptions for the assessment;
- the list of ecosystem services and biodiversity components;
- the traits–services and traits–biodiversity clusters.

The experts were asked to provide their judgement on the probability distribution of the reduction in the level of services provided by the SPU and the level of reduction of specific components of biodiversity.

The experts responded individually to the questionnaire and provided explanations to support their ratings. The collected ratings were combined to provide mixture distributions for the impact on each ecosystem service and biodiversity component subject of the assessment. The mixture distributions were then presented and discussed with the experts, resulting in consensus about the final probability distributions. The final probability distributions represent realistic distributions that adequately integrate the different expert opinions expressed during this consultation.

2.4.4. Spatial distribution of the potential impacts

The resulting estimates of potential impacts have been used to generate high-resolution maps (25 × 25 km) of the spatial distribution of the potential impacts of the apple snail invasion for some ecosystem traits, ecosystem services and biodiversity components.

In future work, the methodology used in this opinion to produce the maps of the spatial distribution of impact on some ecosystem traits, ecosystem services and biodiversity components could also be compared with maps of special wetland areas under Natura 2000 (Council Directive 92/43 EEC[7]). For example, Baker et al. (2012) identified Natura 2000 wetland sites in Spain and Portugal that were climatically suitable for *Eichhornia crassipes.* Although the use of spatial land use data in environmental analysis have limitations (Perennou et al., 2012), CORINE Land Cover Class maps (Bossard et al., 2000) could also be used to help identify and quantify the areas of wetland at risk in the EU. The objective of this comparison would be to visualise the relevant habitats present in the assessment area that are potentially affected by the presence of the apple snail. However, to do this in a scientifically sound way, it would be necessary to relate these maps more clearly to the quantitative analysis of the impacts on ecosystem traits, ecosystem services and the biodiversity components of those habitats considered in the ERA.

3. The scenario assumptions

3.1. Identification of the SPUs

For the definition of the SPU, homogeneity of the type of services the ecosystem provides is important, irrespective of the homogeneity of the environment containing the aquatic plants susceptible to attack by the apple snail (mostly submersed and floating macrophytes). There are differences in the ecology of natural habitats potentially affected by the apple snail (e.g. fresh water wetlands, river deltas), and there are agro-ecological habitats, such as rice paddies, which can be

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[7] Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. OJ L 206, 22.7.1992, p. 7–50.

colonised by *Pomacea*. The term 'wetland' covers a wide range of habitats that are characterised by standing or slowly moving waters, with or without an open body of water. In our ERA, the term wetland is used to describe shallow, aquatic, fresh water systems with standing or slowly moving waters that have an open body of water with a mean depth between 0.2 and 1.0 m for at least six months of the year. In parallel, lentic aquatic systems that have a mean depth of between 1.0 and 2.0 m all year around are defined as shallow lakes, while lentic aquatic fresh waters systems that have a mean depth of more than 2.0 m throughout the year are called lakes.

In order to simplify the application of the ERA, the Panel considers that a single SPU is affected by *Pomacea* spp., i.e. shallow fresh water areas containing macrophytes such as wetlands, shallow lakes, river deltas and the littoral zone of deeper lakes and rivers. The interaction between the SPU and cultivated areas (rice fields) is taken into account in this opinion, but not the cultivated areas themselves. Although the above-mentioned areas are ecologically diverse, they all share a homogeneous environment in which the macrophytes offer retention and processing of nutrients and toxic substances, physical structure, habitat, refuge, food or substrate and an environment for spawning of invertebrates, fish and amphibians. More importantly, these environments share a homogeneity in the type of ecosystem services they provide, which justifies grouping them into a single SPU in our assessment.

3.2. Definition of the spatial and temporal (5–30 years) scales

The potential establishment of the snail in the risk assessment area is expressed in terms of the distribution of snail density. Population density is a very important state variable in ERA as it determines the impact on the ecosystems. For an organism such as *Pomacea*, biomass is more informative than snail density in determining the impact. Therefore, in this opinion, density is expressed in terms of snail biomass per unit area of suitable snail habitat. Because of their trophic activity, only juvenile and adult stages are considered.

In each spatial unit, defined as the cell of the lattice model used to simulate the snail population dynamics, the Panel now computes the potential biomass (*PB*) as the biomass obtained considering the climatic condition in the node, the density-dependent constraints and the additional mortality factor estimated by means of the calibration procedure described in EFSA PLH Panel (2013). Moreover, as explained in the above-mentioned opinion, the role of abiotic factors other than temperature is not explicitly addressed. Because of the width of the trophic niche of the apple snail and the quality and availability of host plants, the Panel does not expect plants to be a limiting factor for establishment.

From the potential biomass (*PB*) estimated by means of the model on potential establishment, the realised biomass (*RB*) is computed considering the effects of resistance, resilience and management, which are regarded as the factors limiting the potential biomass in each spatial unit. The potential biomass is computed for the whole risk assessment area disregarding the presence of suitable habitats. The distribution of the suitable habitats can be overlaid as a different information layer restricting the projection of the population density as well as the expected impact on the areas where snail habitats are really present. This procedure provides a more detailed spatial representation of the impact.

In a first approximation, the effect of the limiting factors is considered homogeneous in the space dimension but variable in the time dimension. This leads to an assessment of the spatial variation of the impact that depends only on the spatial variation of the realised biomass. Snail occurs on a spatio-temporal scale. However, spread of snails is very difficult to predict, owing to the potential but largely unknown role of human-assisted spread and potential long-distance spread by birds (see EFSA PLH Panel, 2013). Therefore, the change in area of potential establishment is disregarded, and the spatial extent of the assessment corresponds to the area of establishment predicted by the population dynamics model. The effects over time of resistance, resilience and management led to the consideration of different scenarios with respect to the temporal scale. The Panel is interested in the effects of *Pomacea* in the short and long term, and, therefore, performed two different assessments:

- A short-term assessment, performed 5 years after establishment, when the population dynamics of the snail has reached its potential maximum level and is mainly influenced by the resistance of the receiving environment and with consideration of the containment and eradication efforts.
- A long-term assessment, performed 30 years after the establishment. At this time horizon a major role is played by the resilience e.g. occurrence of snail-resistant macrophytes and development of control of snails by predators and other natural enemies which need to adapt to the presence of the exotic snail. More specific management measures are expected to be available and will also be considered. Changes in climate and wetland habitats have not been taken into account in the 30-year assessment scenario.

The effects of resistance, resilience and management are discussed in Section 3.4, including a discussion of the evolution of the impact of these factors over time in limiting the snail biomass. Further, the numerical values for the two time horizons are estimated and presented in this section.

3.3. Definition of the biomass scale

To define the biomass scale, the procedure, described in Section 2, and the basic assumptions, specified in Sections 3.1 and 3.2, are modelled, resulting in the quantification of the environmental risk.

Let $PB_i\ t$ be the potential biomass in a cell i at time t obtained by the earlier developed simulation model (EFSA PLH Panel, 2013). PB_i depends on the climatic condition of cell i and changes over time. It requires a certain time to reach the maximum abundance attainable, PB_i^{max}. In the representation of the potential distribution of the invasive species, PB_i^{max} is used.

Three major factors influence the time dynamics of PB_i: the resistance and the resilience of the receiving environment and the management options available to control *Pomacea*. The effects of these factors are modelled by the following functions:

$RS_i(t)$ is a time-dependent scaling factor describing the effect of resistance in cell i.

$RL_i(t)$ is a time-dependent scaling factor describing the effect of resilience in cell i.

$MN_i(t)$ is a time-dependent scaling factor describing the effect of management in cell i.

$RB_i\ (t)$ is defined as the realised biomass in cell i at time t. The realised biomass is obtained from the potential biomass multiplied by the three scaling factors as follows:

$$RB_i\ (t) = PB_i^{max}\ RS_i(t)\ RL_i(t)\ MN_i(t).$$

Under the hypothesis that the effects of resistance, resilience and management are the same in every cell, the realised biomass function $RB_i\ (t)$ becomes

$$RB_i\ (t) = PB_i^{max} RS(t)\ RL(t)\ MN(t).$$

When the values for of resistance, resilience and management are known, scaling factors at different time horizons for the realised biomass can be calculated. In the ERA of invasive species it is relevant to consider at least two time horizons that lead to two different assessments:

- short-term (ts) assessment: performed at time $t = s$, a few years after the establishment (here 5 years);
- long-term (tl) assessment: performed at time $t = l$, normally many years after the establishment, (here 30 years).

In these two scenarios the intensity of the driving force (i.e. the realised biomass of the invasive species) is computed as

$$RB_i\ (ts) = PB_i^{max} RS(ts)\ RL(ts)\ MN(ts).$$

$$RB_i\ (tl) = PB_i^{max} RS(tl)\ RL(tl)\ MN(tl).$$

The next step in the assessment procedure is to define the relationship between the driving force and the ecosystem traits. For each of the selected ecosystem traits, a variable, ET_j, expressing the state of the traits is defined. The state of the variable is normalised to 1, this being the condition characterising the ecosystems before the invasion. It is assumed that the change in the state of ecosystem traits due to the effect of the invasive species depends on the biomass of the driving force only. The driving force is supposed to reduce the value of ET_j, but an increase is also possible. Then, the functions $ET_j = f_j(RB)$, which describe the variation of the state of the ecosystem traits as function of the realised biomass, are estimated by means of a procedure based on the collection of experts' judgement (see Section 4.2). These functions allow the state of the ecosystem traits to be estimated at the two selected time horizons. Under the assumption that the functions $ET_j = f_j(RB)$ do not depend on the cell (i.e. the impact is the same for the whole assessment area), the impact of the invasive alien species on the ecosystem traits for the short term (*ts*) and the long term (*tl*) is defined as

$ET_j(ts) = f_j\big(RB(ts)\big)$; and

$$ET_j(tl) = f_j\big(RB(tl)\big).$$

Having estimated $ET_j(ts)$ and $ET_j(tl)$, two different configurations of ecosystem traits for the two time horizons were obtained. On the basis of the change in the ecosystem traits and the traits–services clusters (see Section 3.4.5), the change in the ecosystem services can be estimated.

3.4. Estimation of resistance, resilience and management

3.4.1. Resistance

The assessment of the environmental consequences of the *Pomacea* spp.-induced transformation of shallow fresh water, macrophyte-dominated ecosystems in Europe must address the interaction between the invader and the receiving communities and ecosystems. The level of ecosystem resistance, i.e. the capability of the ecosystem to remain relatively functionally intact despite the disturbance from *Pomacea* herbivory, is one key variable required to forecast the magnitude of the environmental consequences, especially in the short period after the invasion.

It is important to take into account the fact that fresh water habitats in lowland regions of Europe have been subject to large-scale changes over the last 200 years as a result of an increasing human population, more efficient and nutrient-demanding cultivation and rapid industrialisation in the surrounding catchment areas. These human activities have led to sharp increases in the transport of both suspended particles and nutrients to the fresh water ecosystems and coastal waters in lowland Europe. These changes negatively affect the abundance, diversity and the maximum growing depths of aquatic macrophytes through impoverished light conditions and by promotion of phytoplankton growth (Sand-Jensen et al., 2000). Macrophyte abundance and macrophyte species diversity are therefore steadily declining in Europe (de Nie, 1987). These changes make the shallow fresh water, macrophyte-dominated ecosystems in Europe less resistant to further disturbance.

Herbivory by *Pomacea* has previously been shown to have similar effects on fresh water ecosystems as eutrophication, i.e. a shift from clear water and macrophyte dominance towards turbid waters and increased nutrient concentrations and phytoplankton dominance (Carlsson et al., 2004). It has further been shown that *Pomacea* snails prefer naive North American macrophytes that have not been previously exposed to *Pomacea* herbivory to South American macrophytes that have coevolved with *Pomacea* snails, since the North American macrophytes lack the chemical and physical defences that deter the snails (Morrison and Hay, 2011). In addition, European macrophytes lack a co-evolutionary history with *Pomacea*, and high susceptibility to snail herbivory, and thus very low resistance of the receiving ecosystem, may be expected. Furthermore, the Panel considers it unlikely that natural enemies that are naive to *Pomacea* will be able to control the invasive population and prevent population establishment and growth, at least in the beginning of the invasion. For these reasons, ecosystem resistance to a *Pomacea* invasion is expected to be very low in Europe.

3.4.2. Resilience

The resilience, or the capability of the fresh water ecosystems in Europe to return to their original clear water, macrophyte-dominated state after being disturbed by the effects from a *Pomacea* invasion, may increase over time, as natural enemies may adapt to utilise the new, invasive and abundant resource (Carlsson et al., 2009). However, many fish and bird species that could become important predators of *Pomacea* over time are expected to decline if macrophytes are declining as a result of *Pomacea* herbivory.

3.4.3. Management

Options to reduce and manage apple snail populations were presented in the Spanish pest risk analysis (Spanish Ministry of Environment and Rural and Marine Affairs, 2011) and are discussed in EFSA PLH Panel (2012a). In addition to these options, in the Ebro Delta in Spain, several new management methods have been used recently, such as treatment of rice paddies with lime or saline water. Risk reduction options include legislation to prevent import of the snail into the EU, banning of breeding and trade of the snail, hand or mechanical collection of snails and installation of snail traps. The above-mentioned options are not expected to have serious negative environmental effects and are not discussed later in this section, though they should be considered in the ERA under effects of management on the biomass of apple snail.

The risk reduction options that may cause negative environmental effects on the wetlands are (1) keeping rice paddies dry for long periods, (2) burning vegetation and river bank conditioning and (3) treating rice paddies and/or irrigation canals with (a) lime, (b) saline water, (c) snail attractants containing methaldehyde or (d) saponins.

(1) Keeping rice paddies dry for a long period might negatively influence rice paddy biodiversity, in particular soil biodiversity and birds visiting the rice ecosystem. These effects, when only a small part of all paddies are kept dry at a certain time, are not expected to influence the natural wetland ecosystems near the rice production area.

(2) Burning vegetation and removal of plants along river banks to prevent egg laying and survival of snails will have a negative effect on flora and fauna of river ecosystems in wetlands when applied on a large scale and over several years.

(3) Treating rice paddies with saponins, lime and saline water may result in negative effects on both the rice and the natural wetland ecosystem.

    (a) Application of lime to the paddies will suddenly and strongly increase the pH, and kill not only the snails, but also the majority of invertebrates, fish, amphibians, reptiles, flora and soil life in the rice paddy. Depending on the rice area treated, a further negative effect will be a temporary increase in pH in the rivers and pools of the wetland ecosystem.

    (b) Inundation of paddies with seawater or salt water solutions will also negatively influence the biodiversity of the rice paddy. Depending on the rice area treated with saline water, a temporary negative effect on the river and wetland ecosystem can be expected.

    (c) Use of snail attractants containing methaldehyde to kill the snails is not expected to result in negative environmental effects outside the rice paddies.

(d) Use of saponins will result in a high mortality of many organisms living in rice paddies; saponins are plant-produced glycosides which are highly toxic to fish, molluscs, frogs and other gill-breathing organisms (Joshi et al., 2008; San Martin et al., 2008). As saponins have very short half-lives, 12–24 hours under field conditions according to Hostettmann and Marston (1995), negative effects of their use will mainly occur in the rice paddies and the irrigation canals. The effects on the river and delta ecosystem are expected to be temporary and rather limited.

Some of the methods to control apple snail in rice paddies might also be used in wetlands, e.g. hand or mechanical collection of snails and installation of snail traps, though it is as yet unknown how snail traps affect other biota of wetlands. All the risk reduction options mentioned under 1–3 above seem to result in serious negative effects on wetland ecosystems and, therefore, should not be used.

The negative effects of control measures aimed at apple snail are expected by the Panel to be only a fraction of the negative environmental effects caused by other management methods used to control pests, diseases and weeds in rice production areas. In addition to chemical control of rice pests, diseases and weeds, chemical pesticides as well as microbial control agents are extensively used for control of mosquitoes. Available information on the control of rice pests and mosquitoes suggests that the current methods used to control the apple snail might result in only minor additional negative effects.

Finally, the role of natural enemies in reducing apple snail populations needs to be considered. In the short term, natural enemies are not expected to play an important role, but in the long term several natural enemy species may start to use and even specialise on this abundantly available food source.

Based on the information presented above and on expert estimates, the effect of management measures on reduction of potential snail biomass in fresh water wetlands is estimated to be low in the short term and moderate in the long term.

3.4.4. Scenario parameters

Table 1 summarises the parameters used for the scenarios of the assessment with their confidence intervals.

Table 1: Summary of the scenario parameters used in the assessment

	Short term (ts): 5 years	**Long term (tl): 30 years**
Mean scaling factors		
Resistance (*RS*)	0.9 (CI [0.8242;0.9758]*)	1
Resilience (*RL*)	0.95 (CI [0.9021;0.9979]*)	0.5 (CI [0.3593;0.6407]*)
Management (*MN*)	0.99 (CI [0.9563;1]*)	0.8 (CI [0.6607;0.9393]*)
$RS \times RL \times MN$	0.84	0.4
Biomass		
Maximum potential biomass (PB^{max})	31.5 g/m^2	31.5 g/m^2
Maximum realised biomass (RB^{max})	26.5 g/m^2 (normalised 0.84 g/m^2)	12.6 g/m^2 (normalised 0.40 g/m^2)

*95 % confidence interval for the mean of the scaling factor obtained as described in Appendix A.

3.4.5. Object of the assessment

The ERA scheme here presented offers the possibility to address the assessment at different levels of resolution, considering the impact on the ecosystem traits in relation to snail biomass, the spatial distribution of the impact on the traits and the risk posed to ecosystem services and biodiversity components, and allows also the different types of assessments to be performed independently or in combination. As suggested in the PLH ERA guidance, only the negative impacts of the apple snail on the traits, ecosystems services and biodiversity components have been assessed.

In this study, three different assessments have been performed separately.

The Panel assessed the effect of snail biomass on ecosystem traits for the traits that are presented in Table 2 below and assessed the impact of snail invasion on the ecosystem services in the worst-case scenario. In the context of the current ERA, considering that the driving force of the ecosystem change is the apple snail biomass, some services are not expected to be modified and only the provisioning services and regulating–supporting services listed in Table 3 below have been retained for evaluation.

The Panel also assessed the impact of snail invasion on biodiversity in the worst-case scenario, for both structural and conservation components, which are listed in Table 4. For some of these components of biodiversity, the effect of snail biomass was also evaluated.

Table 2: List of the traits assessed by the Panel

Traits assessed for impact relationship with snail biomass		
Traits related to the macrophytes	**Traits related to water quality**	**Traits related to biodiversity**
Edible macrophyte biomass	Oxygen concentration	Aquatic invertebrates biodiversity
Biomass of non-edible macrophytes	Phosphorus concentration	Amphibian biodiversity
Dominance (macrophytes/phytoplankton)	Sedimentation rate	Fish biodiversity
Macrophyte species diversity	pH (percentage of variation)	Bird biodiversity
Structural complexity of the habitat	Denitrification	Zooplankton biodiversity
		Zooplankton biomass
		Periphyton biomass

Table 3: List of the ecosystem services assessed by the Panel

Ecosystem services assessed for impact of snail invasion	
Provisioning services	**Regulating and supporting services**
Food	Climate regulation
Genetic resources	Water regulation/cycling/purification
Fresh water	Erosion regulation
	Nutrient cycling
	Photosynthesis and primary production
	Pest and disease regulation
	Pollination

Table 4: List of the biodiversity components assessed by the Panel

Biodiversity components assessed for impact of snail invasion
Genetic diversity
Native species diversity
Native habitats, communities and/or ecosystems diversity
Threatened species
Habitats or other ecological entities of high conservation value

In order to systematically assess the impact of snail invasion on the ecosystem services and biodiversity components, the traits–services clusters and traits–biodiversity components clusters presented below (Figures 3 and 4) have been developed by the Panel.

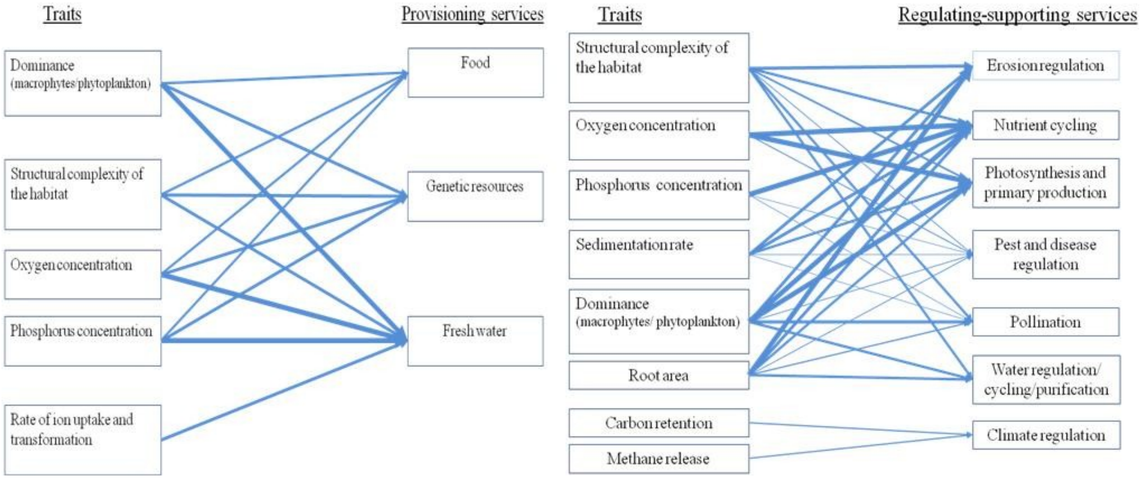


Figure 3: Traits–services clusters

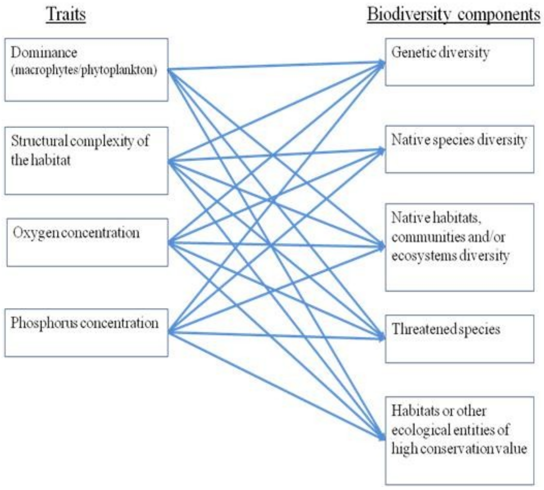


Figure 4: Traits–biodiversity components clusters

4. Environmental risk assessment

4.1. Projection of the potential and realised biomass

Starting from the maps representing the potential snail density in Europe (individuals/m²), it is possible to obtain maps for the potential biomass (g/m² of fresh weight) of *Pomacea*, by considering the weighted mean weight for the juvenile and adult stages, i.e. taking into account the duration and the survival of the stages. Mean juvenile weight is 3.6 g (Estebenet and Martín, 2003) and mean adult weight is 7.8 g (Y. Liu et al., 2011). The realised biomass is then obtained by multiplying the potential biomass by the mean values of resistance, resilience and management which were estimated by the experts (Table 1).The experts also individually estimated for each scaling factor an interval in which the mean value of the corresponding scaling factor falls with 95 % of probability (see Section 2.4.1 and Appendix A). This interval takes into account the uncertainty in the estimated mean value. Next, the estimates of the experts are combined to obtain a single 95 % confidence interval for the mean of each scaling factor. Finally, several maps were compiled. The first map (Figure 5) shows the translation from snail numbers to total potential biomass of *Pomacea* (Figure 2a and b above). Then, three types of maps were compiled for each of the two time horizons: one map is based on the multiplication of the potential biomass by the mean values of the scaling factors; the other two maps are based on multiplication of the potential biomass by the lower bounds (less favourable scenario for snails) or the upper bounds (more favourable scenario for snails) of the scaling factors. The maps based on lower and upper bounds account for the effects of uncertainty in the scaling factors on the distribution of biomass.

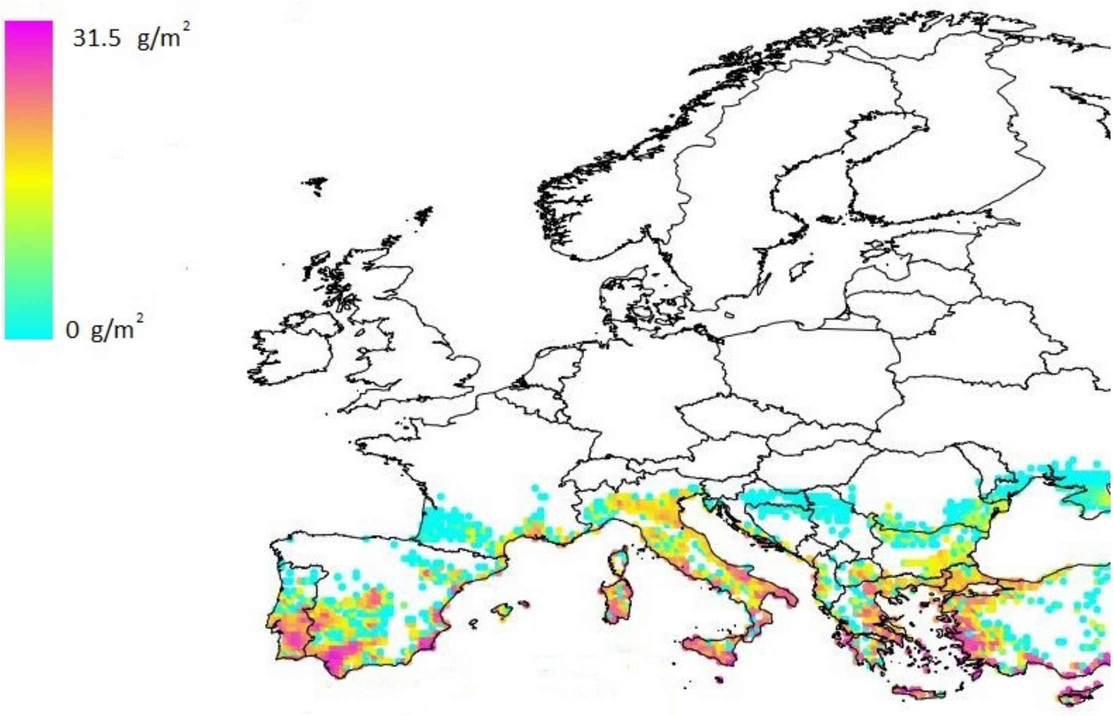
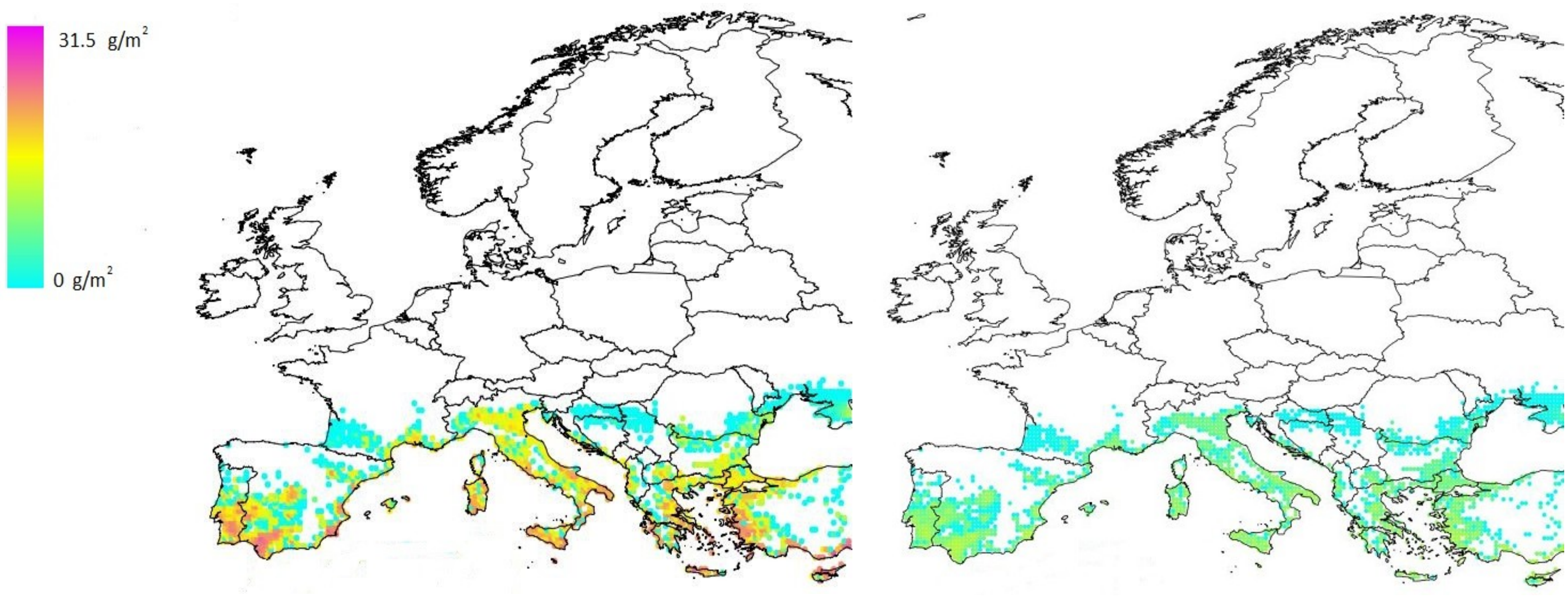


Figure 5: Distribution of total potential biomass (g/m²) of *Pomacea canaliculata* juveniles + adults over Europe. The colour code in the legend corresponds to biomass values above 0.

High biomass values (more than 20 g/m²) are predicted for a large number of coastal and inland Mediterranean locations. However, when the potential biomass is multiplied by the values of the scaling factors (resistance, resilience, management), the average realised biomass for the 5 (Figure 6a) and 30 (Figure 6b) years time horizon is considerably lower. The average realised biomass for the 30 years time horizon is lower than that of the 5 years time horizon, since it is expected that (i) macrophytes which are non-palatable to *Pomacea* will replace some of the palatable macrophytes, which will largely disappear, and (ii) natural enemies may reduce snail numbers more efficiently at the longer time horizon as less food is available for snails.

Figure 6a shows that quite a number of locations have a high average realised biomass; however, this number is significantly lower than in the graph showing total potential biomass (Figure 5). In Figure 6b, which represents the average realised biomass after a 30 years time horizon, biomass values no longer reach the highest classes.

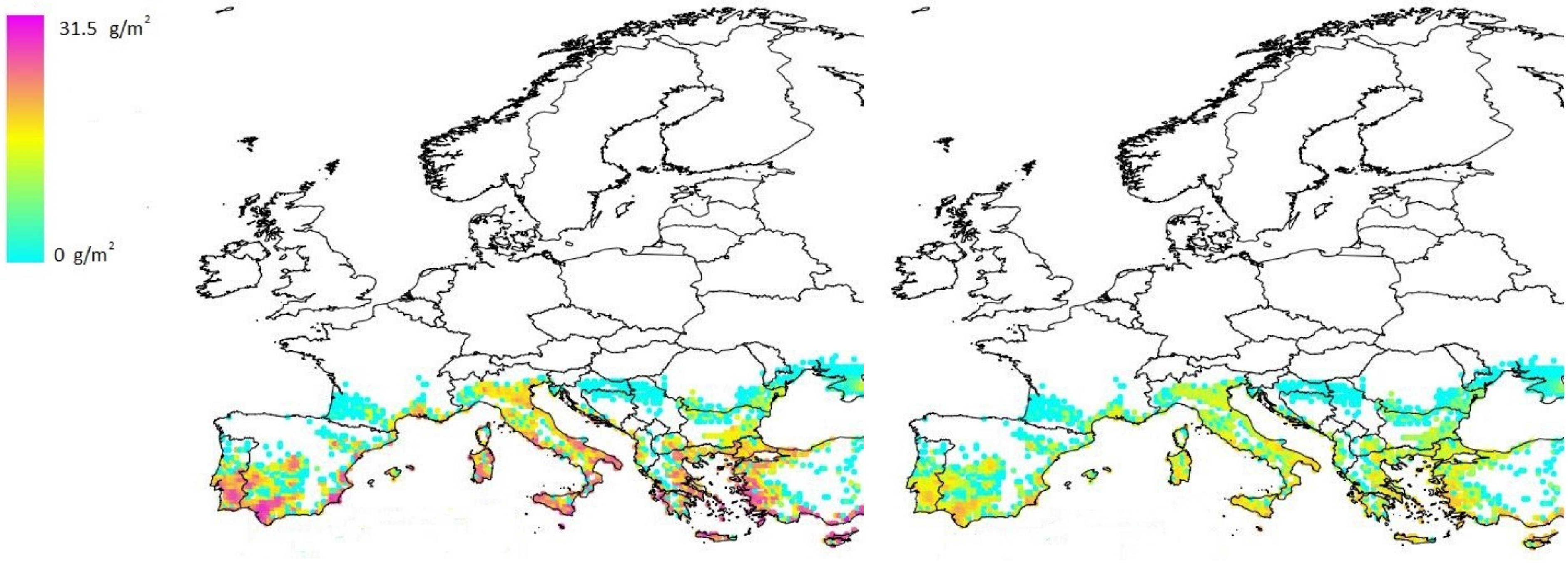
In Figure 7b (5 years time horizon) and Figure 8b (30 years time horizon), the realised biomass is shown for a scenario in which the potential biomass is multiplied by the lower limits of the 95 % confidence intervals of the three scaling factors, corresponding to the less favourable scenario for the snails. As expected, the biomass values are lower than in Figure 6a and b, which shows the average realised biomass. In Figure 7a (5 years time horizon) and Figure 8a (30 years time horizon), the realised biomass is shown for a scenario in which the potential biomass is multiplied by the upper limits of the 95 % confidence intervals of the three scaling factors corresponding to the more favourable scenario for the snails. As expected, in this case the biomass values are higher than in Figure 6a and b, which shows the average realised biomass.



a. 5 years, average realised biomass

b. 30 years, average realised biomass

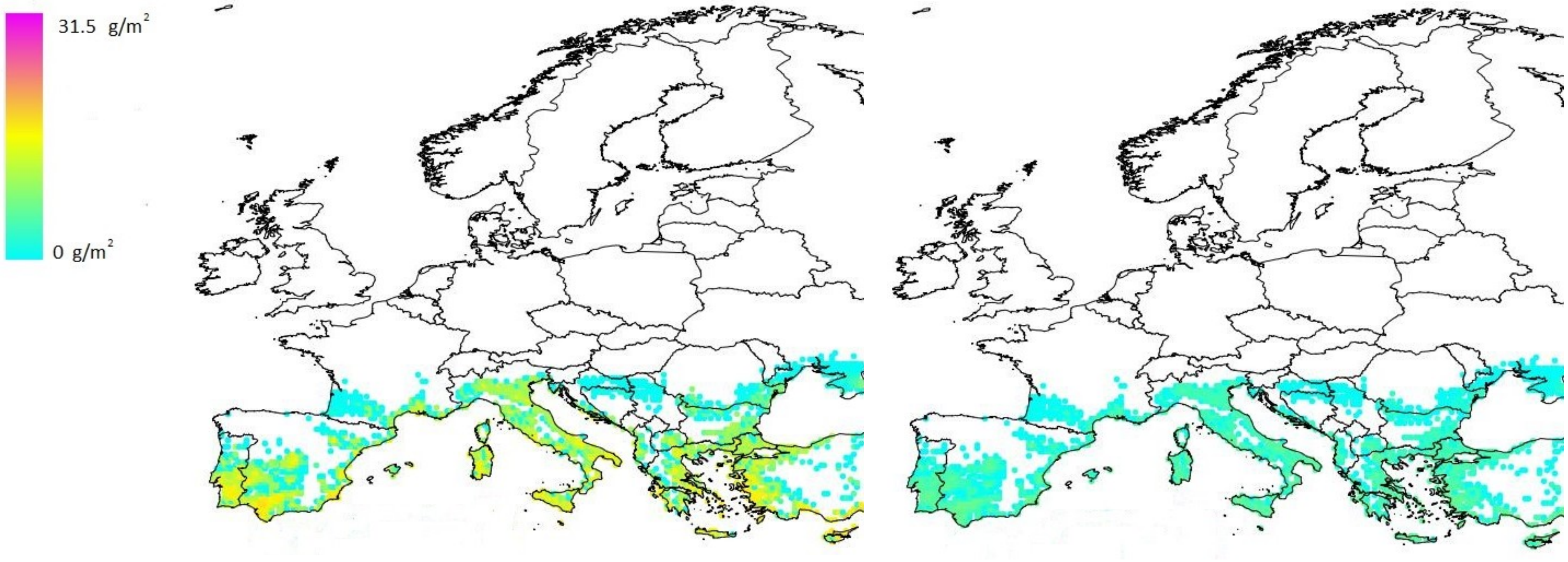
Figure 6: Distribution of average realised biomass (g/m²) of *Pomacea canaliculata* juveniles + adults over Europe estimated obtained by multiplying the potential biomass by the values of the scaling factors (resistance, resilience, management) estimated for two time horizons: (a) average realised biomass after 5 years; (b) average realised biomass after 30 years.



a. 5 years, more favourable scenario for snails

b. 5 years, less favourable scenario for snails

Figure 7: Distribution of realised biomass (g/m²) of *Pomacea canaliculata* juveniles + adults over Europe estimated with a time horizon of 5 years for two scenarios, obtained by multiplying the potential biomass by the limits of the 95 % confidence intervals of the three scaling factors: (a) upper limits corresponding to the more favourable scenario for the snails; (b) lower limits corresponding to the less favourable scenario for the snails.



a. 30 years, more favourable scenario for snails **b. 30 years, less favourable scenario for snails**

Figure 8: Distribution of realised biomass (g/m²) of *Pomacea canaliculata* juveniles + adults over Europe estimated with a time horizon of 30 years for two scenarios, obtained by multiplying the potential biomass by the limits of the 95 % confidence intervals of the three scaling factors: (a) upper limits corresponding to the more favourable scenario for the snails; (b) lower limits corresponding to the less favourable scenario for the snails.

4.2. Effects of snail biomass on ecosystem traits

In this section, the effect of snail biomass on ecosystem traits is assessed and the results are presented in the form of histograms, which are in a number of cases accompanied by maps showing the spatial distribution of the impact on traits in the assessment area. The uncertainty associated with each trait–biomass relationship was not assessed.

The values of the variable *ET* as function of snail biomass for the different ecosystem traits were obtained by means of a procedure based on the collection of expert's judgement. During this procedure, the experts provided an agreed value for each trait with respect to the realised biomass normalised to 1 for the levels of 0 (no snails), 0.25, 0.5, 0.75 and 1. The reference level of the ecosystem trait is the state of the SPU without perturbation, and its value is equal to 1. The value of the variable *ET* is greater than or equal to zero. If the value is equal to zero, the level of the trait reduces to zero (i.e. there is a high impact on the ecosystem trait); if the value is equal to 1, the trait does not change (i.e. there is no impact on the trait). The level of the trait increases as the variable increases above 1. Next, the estimated values of the function *ET* provided by the experts for the levels of 0 (no snails), 0.25, 0.50, 0.75 and 1 were interpolated by means of a continuous function. The spatial distribution of the impact on ecosystem traits is evaluated by means of the value of the interpolating function in each node of the simulation grid, hereinafter referred to as index I_{ET}, for the realised snail biomass in the node.

The same procedure for the estimation of *ET* and the index I_{ET} was applied for some of the biodiversity components. The results are presented in Section 4.4.

4.2.1. Traits related to the macrophytes

At high snail density, sharp reductions in most palatable macrophyte species may be expected. Carlsson et al. (2004) demonstrated that invasion by *P. canaliculata* in Asian wetlands can dramatically reduce both the species richness and abundance of macrophytes. Macrophytes play a key role in nutrient cycling and act as important natural 'biofilters' that ensure minimum water quality in fresh water ecosystems (Petr, 2000; Carlsson, 2006). Their nutrient cycling hampers phytoplankton growth and, subsequently, prevents the development of harmful and extremely costly toxic algal blooms (Pretty et al., 2003). Macrophytes are therefore key components in the wastewater treatment of both natural and constructed wetlands (Brix, 1994), and, furthermore, are a potent, eco-friendly and cost-efficient tool in the phytoremediation processes (i.e. whereby aquatic macrophytes remove or inactivate harmful heavy metals from industrial effluents (Haberl et al., 1995; Rai, 2009)). As a result of all these features, both the amount of macrophytes and macrophyte species richness are important for the self-cleaning functioning in these wetlands (Engelhardt and Ritchie, 2001) and, as *Pomacea* spp. herbivory affects both negatively, a *Pomacea* infestation will also remove these water-cleaning functions in wetlands. Therefore, wetlands are nowadays often protected and restored to create macrophytes-dominated wetland systems, and many countries in Europe have initiated extensive wetland construction programmes (Hansson et al., 2005).

4.2.1.1. Edible macrophyte biomass

Macrophytes species with high contents of phenolic compounds and relatively low contents of nutrients (low C/N ratio) are generally less palatable to *Pomacea*, and some macrophytes are not consumed at all. In the long term these few species are likely to increase as a result of reduced competition from other macrophytes. Horgan et al. (2014) reviewed a number of studies assessing the effects of invasive *Pomacea* snails on natural and managed wetlands and predicted that 'apple snails will shift macrophyte communities towards dominance by chemically and physically (high dry weight) defended plants. In most cases these will be emergent plants and the more palatable submerged and floating species are expected to decline. However, recruitment of emergent flora will also be affected by snails if seedlings and younger plants are vulnerable to snail herbivory'. Interestingly, Qiu et al. (2011) showed that non-palatable plants may become more palatable when senescent. So, even if a macrophyte is non-palatable when healthy and vigorous, the old and rotten leaves and stems may help to support *Pomacea* populations. Another interesting recent finding is that snail feeding may induce chemical plant defence in some of the palatable plant species, resulting in reduced snail feeding and slower growth (Morrison and Hay, 2011).

Based on the information in the histogram below (Figure 9) and in Figure 10a and b, the Panel concludes that in both the short term and the long term, the impact of increasing snail biomass on edible plant biomass is very serious in a large part of the Mediterranean area.

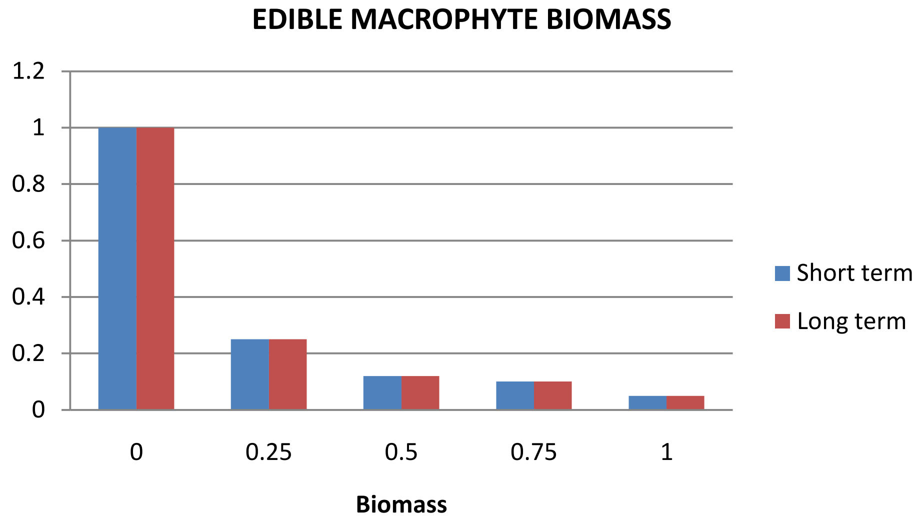
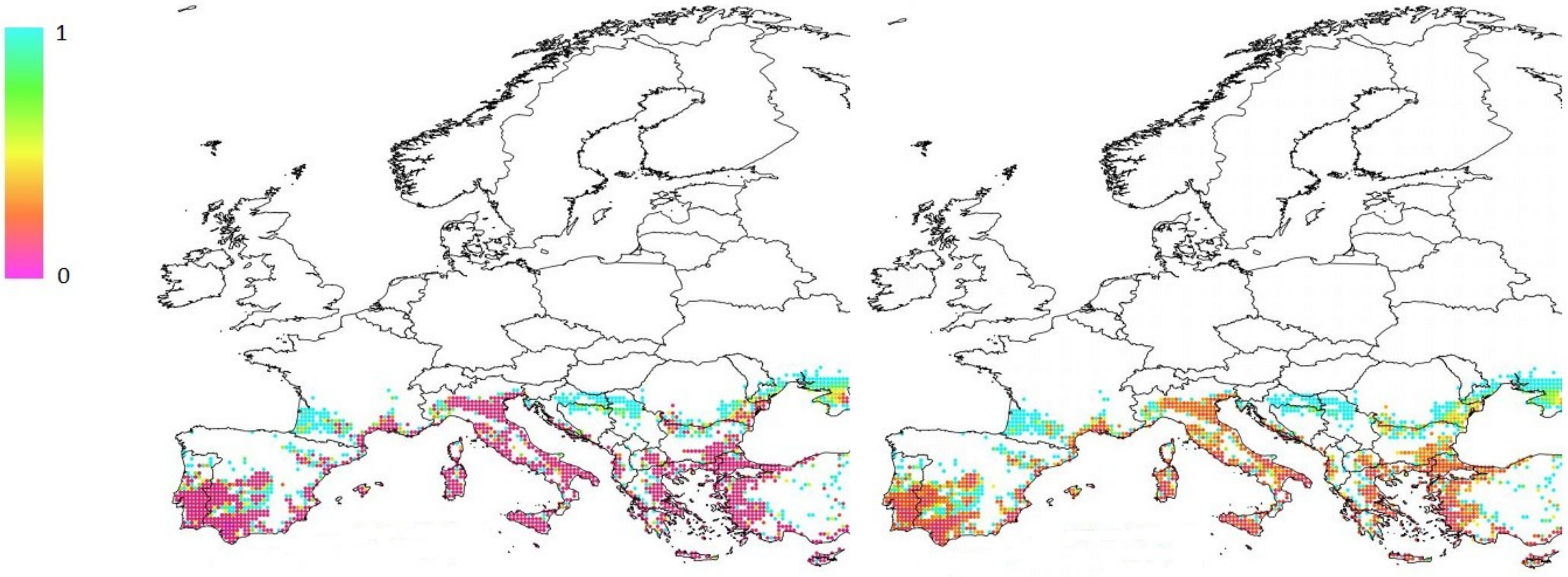


Figure 9: Reduction in edible macrophyte biomass due to the effect of snail biomass (x-axis). y-axis: the value of the variable *ET* in the short (5 years) and long term (30 years), as estimated by experts.



a. 5 years **b. 30 years**

Figure 10: Distribution of the index I_{ET} representing the change in the edible plant biomass due to the effects of the realised snail biomass at the two time horizons. Values of the index close to zero correspond to high impact on the ecosystem trait, while values of the index close to 1 denote a low impact: (a) 5 years, short term; (b) 30 years, long term.

4.2.1.2. Biomass of non-edible macrophytes

Non-edible plant biomass will increase over time, as indicated in the histogram (Figure 11) below and explained in Section 4.2.2.1. Accordingly, the index I_{ET} is greater than 1.

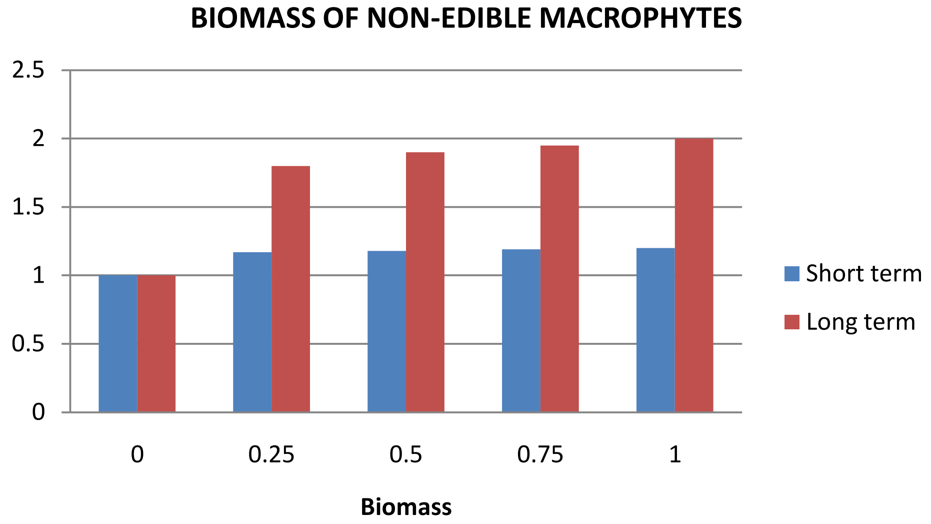


Figure 11: Increase in the biomass of non-edible macrophytes due to the effect of snail biomass on edible macrophytes. The y-axis shows the value of the variable *ET* in the short and long term, as estimated by experts, for the levels 0 (no snails), 0.25, 0.5, 0.75 and 1 of the realised biomass normalised to 1 (on the x-axis).

4.2.1.3. Dominance (macrophytes/phytoplankton)

At high snail density, sharp reductions in most palatable macrophyte species and an increasing shunting of nutrients from aquatic macrophytes to phytoplankton may be expected. This process may lead to a drastic ecosystem shift from clear water and aquatic macrophyte dominance to turbid water and dominance by planktonic algae. Such shifts have attracted much attention in aquatic ecology since they are quite stable and not easily reversible (Scheffer et al., 1993). These shifts are typically mediated by high nutrient loads (Scheffer, 1998), but they have also been shown to be driven by herbivory from *P. canaliculata* (Carlsson et al., 2004), as well as by invasive carp and crayfish (Shin-Ichiro et al., 2009).

Based on the information in the histogram below (Figure 12) and in Figure 13a and b, the Panel concludes that, in the short term, the impact of increasing snail biomass on dominance (macrophytes/phytoplankton) is quite serious in a large part of the Mediterranean area, and that the effect is less serious in the long term, owing to the increased occurrence of non-edible macrophytes.

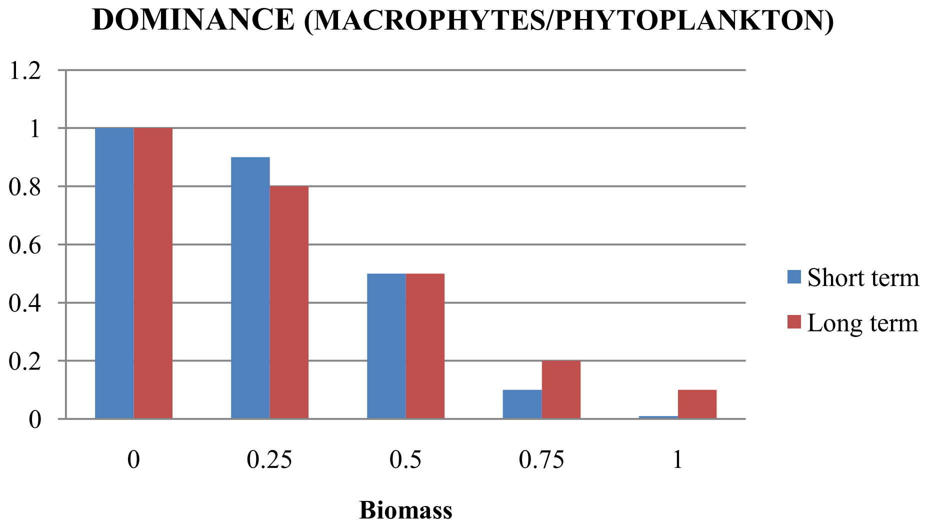
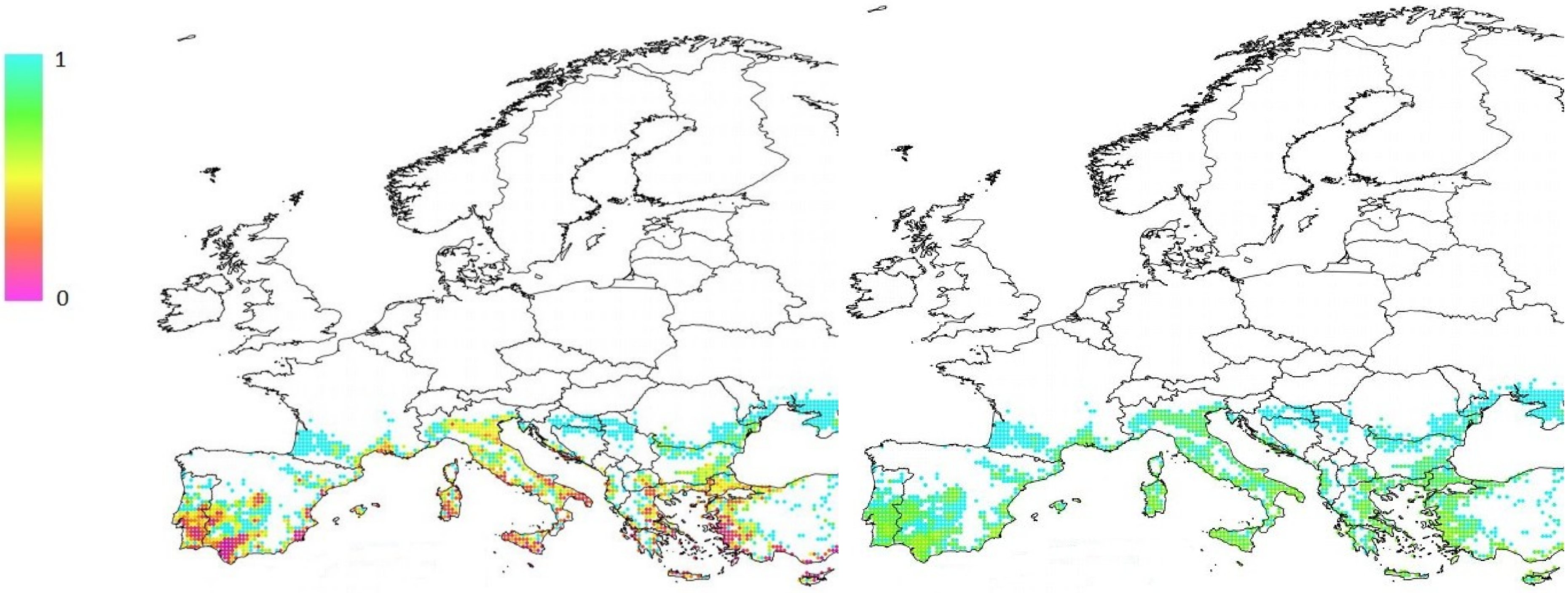


Figure 12: Increase in macrophytes dominance (macrophytes/phytoplankton) due to the effect of snail biomass on edible macrophytes. The y-axis shows the value of the variable *ET* in the short and long term, as estimated by experts, for the levels 0 (no snails), 0.25, 0.5, 0.75 and 1 of the realised biomass normalised to 1 (on the x-axis).



a. 5 years **b. 30 years**

Figure 13: Distribution of the index I_{ET} representing the change in macrophytes dominance (macrophytes/phytoplankton) due to the effects of the realised snail biomass at the two time horizons. Values of the index close to zero correspond to high impact on the ecosystem trait, while values of the index close to 1 denote a low impact: (a) 5 years, short term; (b) 30 years, long term.

4.2.1.4. Macrophyte species diversity

Carlsson et al. (2004) demonstrated that invasion by *P. canaliculata* in Asian wetlands can dramatically reduce the species richness of macrophytes.

Based on the information in the histogram below (Figure 14) and in Figure 15a and b, the Panel concludes that, in the short term, the impact of increasing snail biomass on macrophyte species is quite serious in a large part of the Mediterranean area, and that the effect is less serious in the long term, owing to the increased occurrence of non-edible macrophytes and some re-colonisation of edible macrophytes at lower realised snail biomass.

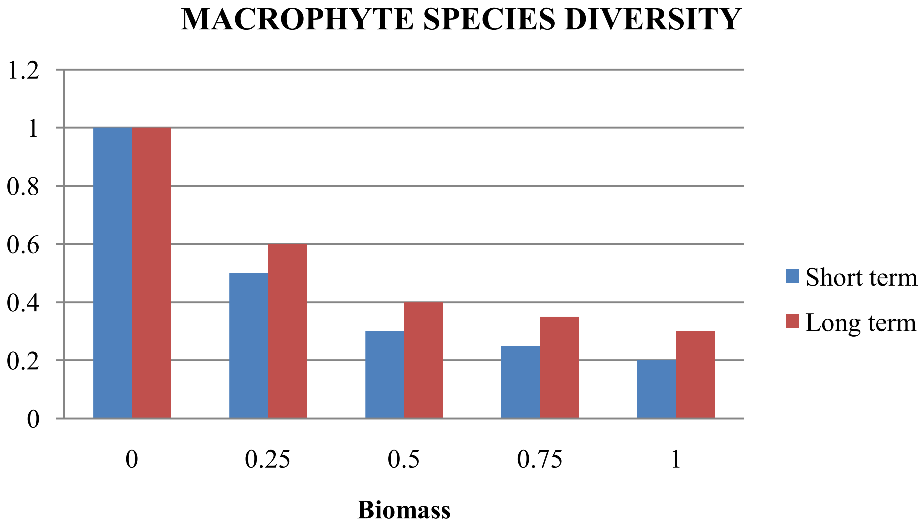
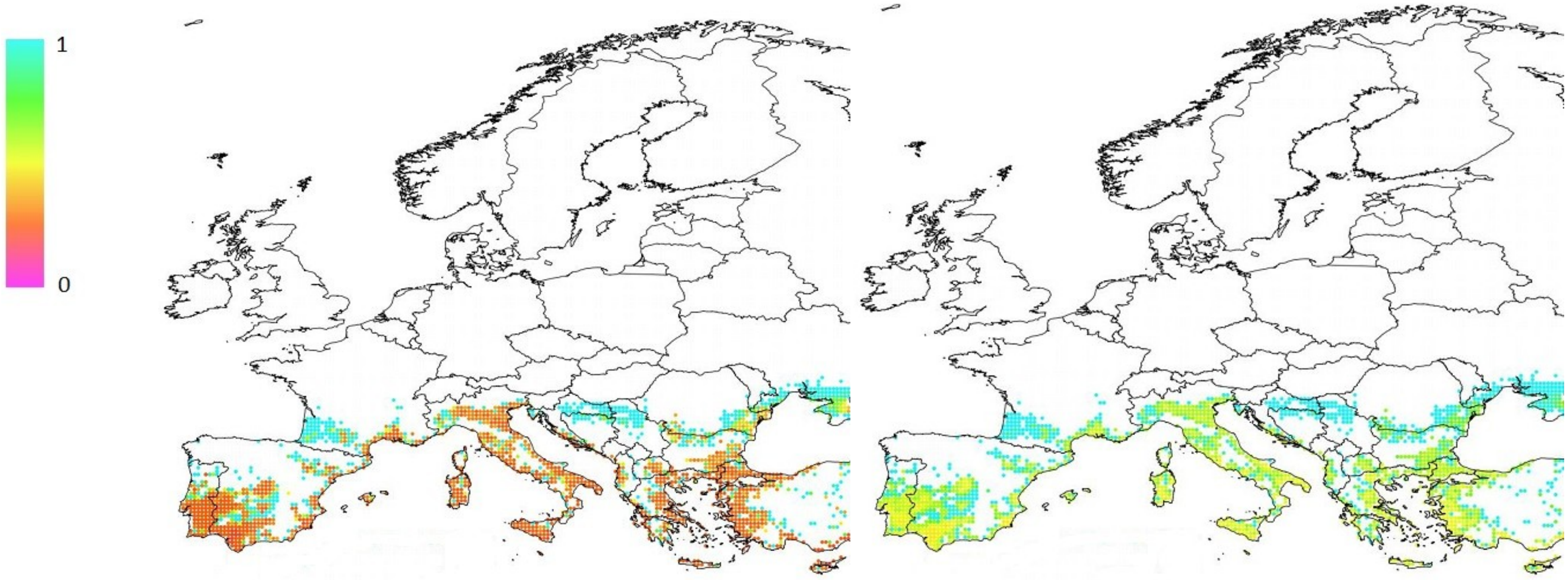


Figure 14: Change in macrophyte species diversity due to the effect of snail biomass. The y-axis is shows the value of the variable *ET* in the short and long term, as estimated by experts, for the levels 0 (no snails), 0.25, 0.5, 0.75 and 1 of the realised biomass normalised to 1 (on the x-axis).



a. 5 years

b. 30 years

Figure 15: Distribution of the index I_{ET} representing the change in the macrophyte species diversity due to the effects of the realised snail biomass at the two time horizons. Values of the index close to zero correspond to high impact on the ecosystem trait, while values of the index close to 1 denote a low impact: (a) 5 years, short term; (b) 30 years, long term.

4.2.1.5. Structural complexity of the habitat

Macrophytes provide varied and structurally complex habitats (Dielh, 1988, 1992; Persson and Crowder, 1998; Petr, 2000). According to Carlsson et al. (2004), when *Pomacea* snails consume macrophytes, structural complexity is expected to decline as a function of *Pomacea* biomass. The histogram below (Figure 16) shows the expected decline in complexity to be quite serious in the short term and somewhat less serious in the long term owing to recovery of mainly non-edible macrophytes.

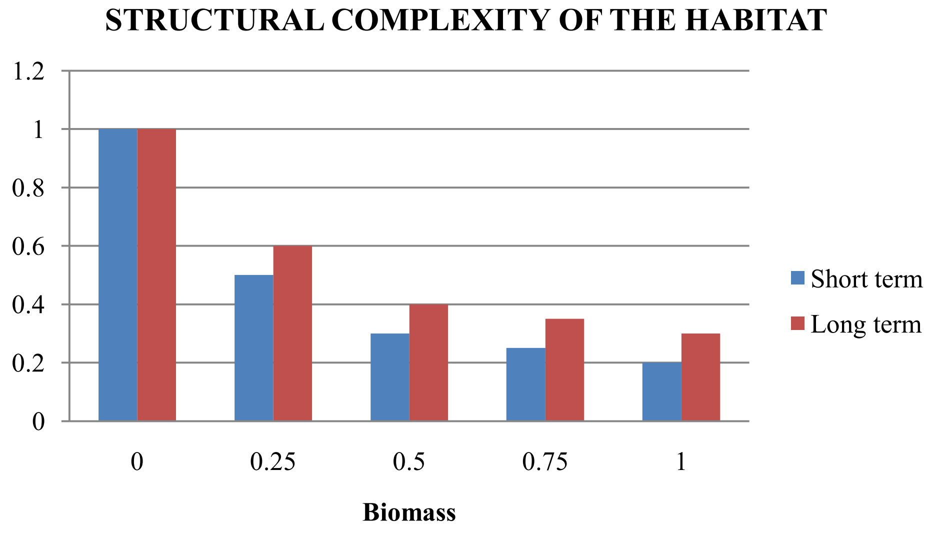


Figure 16: Change in structural complexity of the habitat due to the effect of snail biomass. The y-axis shows the value of the variable *ET* in the short and long term, as estimated by experts, for the levels 0 (no snails), 0.25, 0.5, 0.75 and 1 of the realised biomass normalised to 1 (on the x-axis).

4.2.2. Traits related to water quality

Nowadays, one of the most severe threats to water quality in aquatic ecosystems is the high nutrient load resulting from anthropogenic activities. Due to high nutrient input levels of nitrogen and phosphorus leading to eutrophication, many aquatic ecosystems shift into dominance by (toxic) algae, as discussed above. Because macrophytes directly assimilate nitrogen, phosphorus and heavy metals, they provide wetlands with resistance to increasing nutrient loads. Macrophytes further impede water movement and increase sedimentation of particle-bound substances, which allows nutrients and harmful substances to be processed, or buried permanently, in the sediment. They reduce nitrogen levels by providing a huge substrate for perythic algae that host denitrifying bacteria that transform nitrate to N_2 gas, which leaves the wetland. They remove phosphorus by facilitating processes such as sorption, precipitation and direct uptake (with subsequent harvest) and peat/soil accretion (Vymazal, 2007).

The above-mentioned functions of macrophytes will be reduced after infestation by herbivorous *Pomacea snails*. When the water flow is no longer impeded by macrophytes, sedimentation is drastically lowered and the sediments become less stable and more likely to be re-suspended by water and wind movements (Koch, 2001). Declines in macrophytes lead to subsequent increases in phytoplankton concentrations, and their later decaying consumes large amounts of oxygen. When the sediment surface becomes anoxic, phosphorus is no longer chemically bound to the sediment and instead released to the water column, promoting new algal blooms.

The most serious consequence of *Pomacea* herbivory on water quality occurs when aquatic ecosystem that already receive high nutrient loads are pushed into a drastic shift from clear water and aquatic plant dominance to turbid water and dominance by planktonic algae. As discussed earlier, such shifts are not easily reversible (Scheffer et al., 1993), and collapse of the inland nutrient retention capacity may generate harmful algal blooms in coastal regions too. There is growing concern worldwide about the increasing occurrence of algal blooms (Landsberg, 2002), considering the public health consequences of toxic algal blooms (Chorus and Bartram, 1999) and the lethal effects of toxic algal blooms on aquatic birds and mammals (Landsberg, 2002; Anderson, 2009). The cost of treating drinking water affected by algal blooms is also enormous, as are the losses of recreational and touristic values (Pretty et al., 2003).

Eutrophication is an ongoing process that is linked to a growing human population and increased aerial deposition, waste water input and run-off from fertilised farmlands that affect macrophytes negatively and promote algal blooms. *Pomacea* snails not only accelerate this ongoing degradation of the aquatic ecosystems, but also make this undesirable shift less reversible. Once macrophytes are consumed, it is no longer possible to remove nutrients or toxic heavy metals from the system by harvesting macrophytes. Efforts to decrease nutrient inputs to fresh water systems through improved wastewater treatment and changed farming practices will also be less effective in promoting clear water and macrophyte dominance if the macrophytes are consumed by *Pomacea*.

The secondary effects of *Pomacea* on water quality are far-reaching and very important for both biodiversity and the human population in Europe. The most important consequence of *Pomacea* infestation is thought to be the removal from wetlands and other shallow fresh water/brackish water bodies of macrophytes, which are highly important components of healthy aquatic ecosystems, ensuring good water quality. Therefore, the Panel presents below a more detailed scenario analysis of the possible consequences of the removal of macrophytes by snails.

It should be clarified, however, that processes such as nutrient retention in fresh water ecosystems are complex and influenced not only by the abundance and species diversity of macrophytes, but also by the magnitude and type of nutrient load, water depth, sediment composition and several other factors. Since it is beyond the scope of this ERA to address this complexity in detail, the Panel instead discusses the potential consequences of drastic reductions in macrophyte abundance and macrophyte species diversity in the context of the documented role of aquatic macrophytes in processes related to water quality.

The retention time of water at larger geographic scales is expected to decrease slightly if aquatic plants decline since beds of aquatic plants physically impede water movement.

4.2.2.1. Oxygen concentration

When large quantities of dead matter (plant, phytoplankton or other biomass) are decaying at the sediment surface large amounts of oxygen is consumed by decomposing bacteria. The histogram below (Figure 17) shows that the impact of increasing snail biomass on oxygen concentration is quite serious in the short and long term.

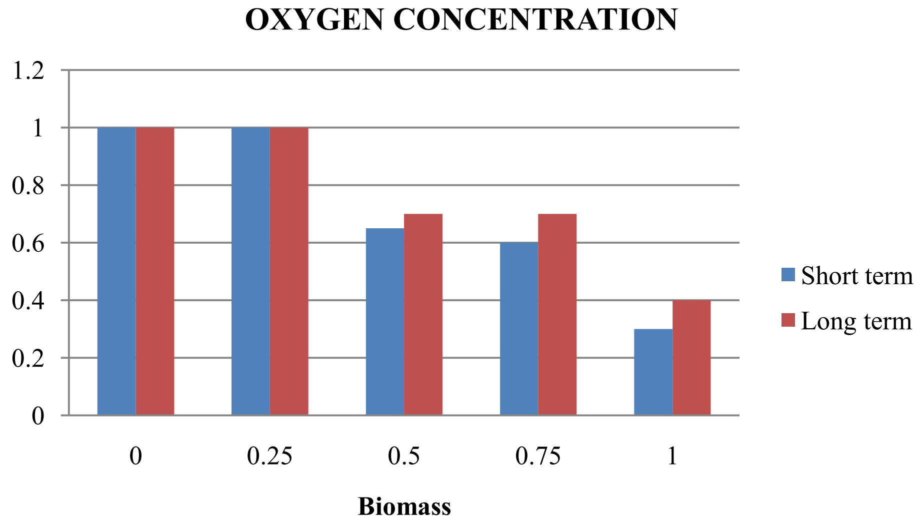


Figure 17: Change in oxygen concentration due to the effect of snail biomass. The y-axis shows the value of the variable *ET* in the short and long term, as estimated by experts, for the levels 0 (no snails), 0.25, 0.5, 0.75 and 1 of the realised biomass normalised to 1 (on the x-axis).

4.2.2.2. Phosphorus concentration

When the sediment surface becomes anoxic, phosphorus is released into the water column. Since the internal phosphorus load is the principal component of phytoplankton growth in shallow lakes and wetlands (Istvánovics et al., 2004), this may induce algal blooms that further increase oxygen consumption, as blooming phytoplankton soon die, sediment and are decomposed by oxygen-consuming bacteria. The following increase in oxygen consumption then promotes further internal load of phosphorus to the water column and, subsequently, new algal blooms. The histogram below (Figure 18) shows that increasing snail biomass has a serious impact on phosphorus concentration, but that the effects are less serious in the long term than in the short term.

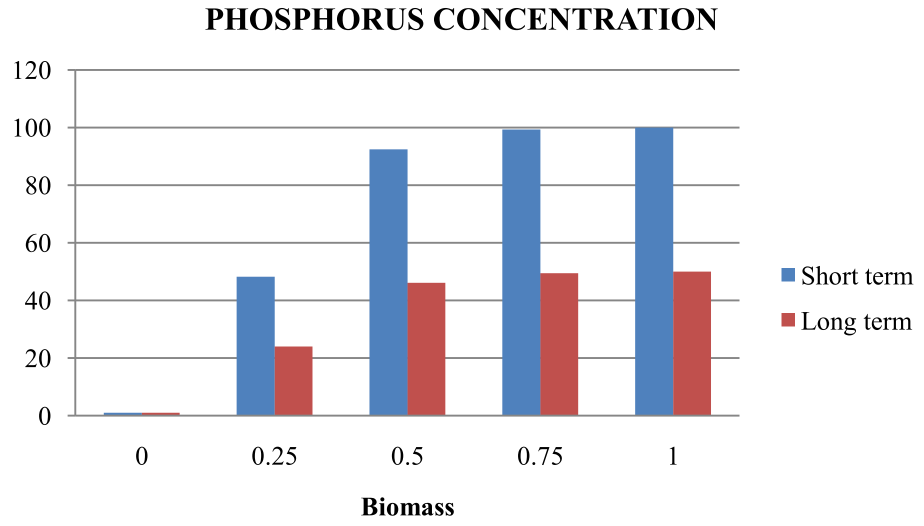


Figure 18: Change in phosphorus concentration due to the effect of snail biomass. The y-axis shows the value of the variable *ET* in the short and long term, as estimated by experts, for the levels 0 (no snails), 0.25, 0.5, 0.75 and 1 of the realised biomass normalised to 1 (on the x-axis).

4.2.2.3. Sedimentation rate

The sedimentation rate is expected to decrease since suspended particles sediment faster when the water is impeded by dense beds of macrophytes and more slowly if the macrophytes are consumed. The histogram below (Figure 19) indicates a serious effect of increasing snail biomass on the sedimentation rate in both the short and long term.

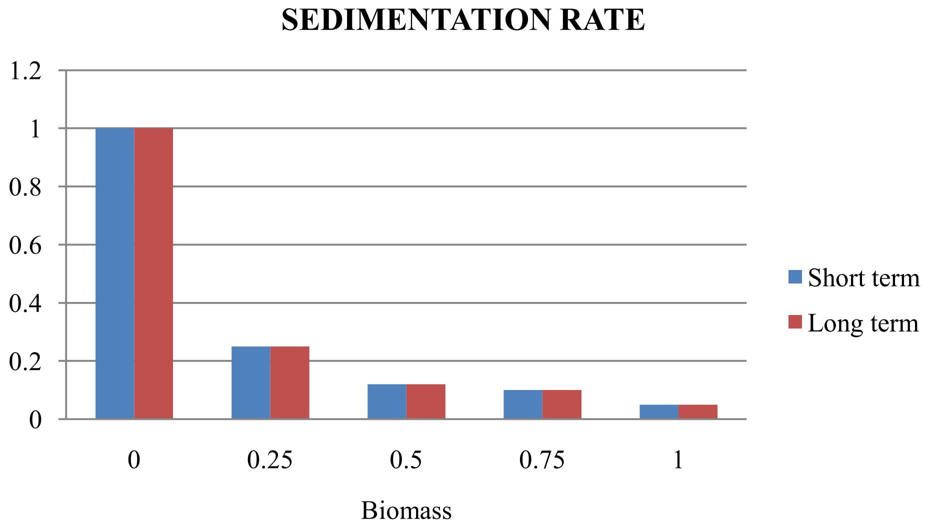


Figure 19: Change in sedimentation rate due to the effect of snail biomass. The y-axis shows the value of the variable *ET* in the short and long term, as estimated by experts, for the levels 0 (no snails), 0.25, 0.5, 0.75 and 1 of the realised biomass normalised to 1 (on the x-axis).

4.2.2.4. pH (percentage of variation)

Intense phytoplankton production may raise the pH of the water to toxic levels. The histogram below (Figure 20) indicates that, with increasing snail biomass, the pH will remain the same or increase in both the short and long term.

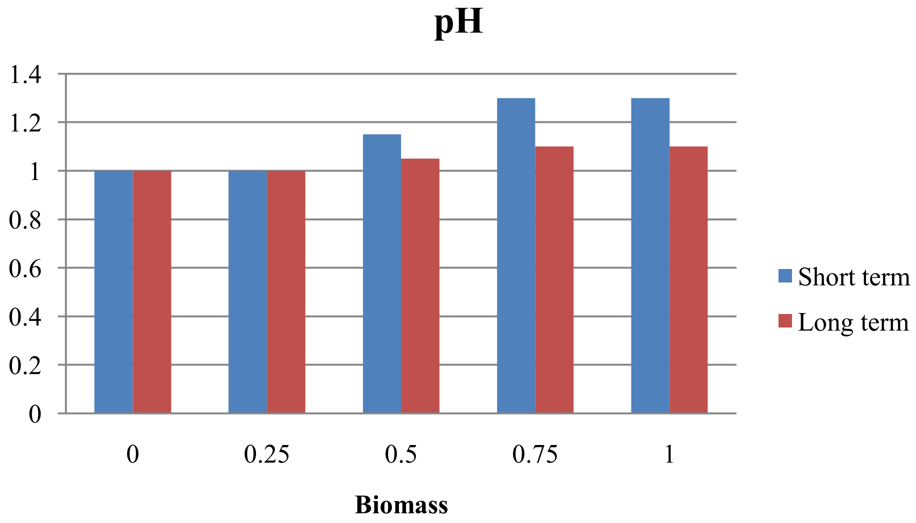


Figure 20: Change in the pH of the water (in %) due to the effect of snail biomass. The y-axis shows the value of the variable *ET* in the short and long term, as estimated by experts, for the levels 0 (no snails), 0.25, 0.5, 0.75 and 1 of the realised biomass normalised to 1 (on the x-axis).

4.2.2.5. Denitrification

Macrophytes reduce nitrogen levels by providing a huge substrate for periphytic algae that host denitrifying bacteria that transform nitrate into N_2 gas, which leaves the wetland. The histogram below (Figure 21) indicates that increasing snail biomass has a serious impact on denitrification in the short term and a somewhat less serious impact in the long term.

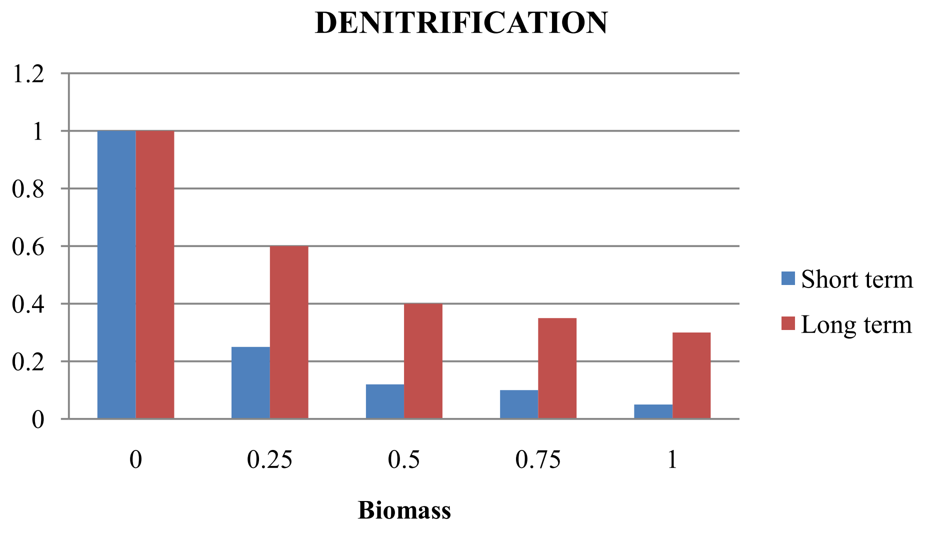


Figure 21: Change in the denitrification rate due to the effect of snail biomass. The y-axis shows the value of the variable *ET* in the short and long term, as estimated by experts, for the levels 0 (no snails), 0.25, 0.5, 0.75 and 1 of the realised biomass normalised to 1 (on the x-axis).

4.2.3. Traits related to biodiversity

At a general level, macrophytes maintain biodiversity by providing varied and structurally complex habitats for macroinvertebrates, zooplankton and juvenile fish (Dielh, 1988, 1992; Persson and Crowder, 1998) and serve as food or the substrate for food (periphyton) consumed by macroinvertebrates (James et al., 2000), fish and waterfowl (Lodge et al., 1998). Reductions in macrophyte species richness and macrophyte abundance will negatively affect all resident and transient organisms that depend on macrophytes at any life stage.

4.2.3.1. Aquatic invertebrates biodiversity

Besides the loss of structurally complex habitats, macrophyte for food and macrophytes as substrate for food, *Pomacea* snails further reduce populations of several benthic organisms through direct predation (Horgan et al., 2014). *Pomacea* species feed on living invertebrates, for example worms, microcrustaceans, bryozoans (Wood et al., 2006), and on other snails (Guimarães, 1983; Cazzaniga, 1990; Hofkin et al., 1991; Stryker et al., 1991; Aditya and Raut, 2002; Estebenet and Cazzaniga, 1992; Wood et al., 2006; Kwong et al., 2010). The histogram below (Figure 22) indicates that increasing snail biomass has a serious impact on invertebrate biodiversity in both the short and long term.

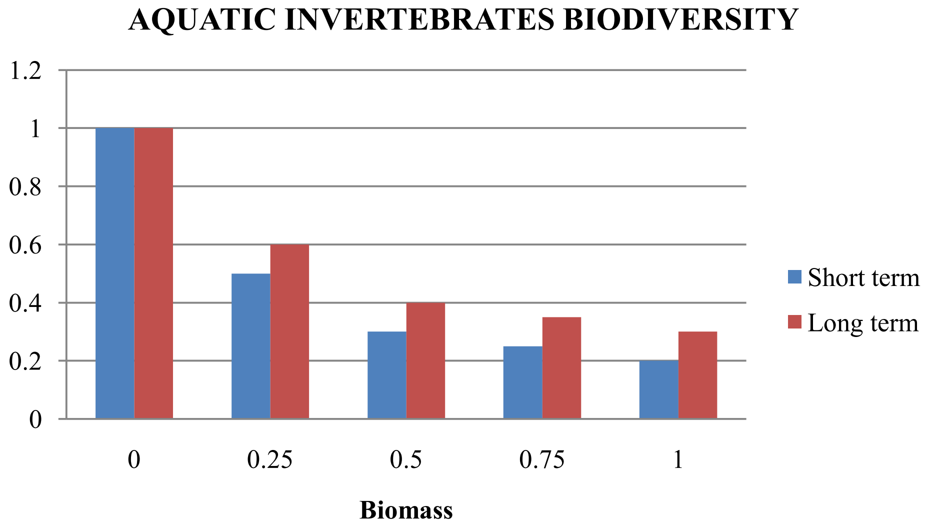


Figure 22: Change in the aquatic invertebrates biodiversity due to the effect of snail biomass. The y-axis shows the value of the variable *ET*, in the short and long term, as estimated by experts, for the levels 0 (no snails), 0.25, 0.5, 0.75 and 1 of the realised biomass normalised to 1 (on the x-axis).

4.2.3.2. Amphibian biodiversity

General autecology of amphibian species in the risk assessment area allows us to predict reductions in reproductive success since amphibians, like many fish species, wrap their eggs around aquatic plants, where, in contrast to the sediments, oxygen is sufficient for further development. Low coverage of submersed macrophytes has been correlated with lower reproductive success in amphibians (Nyström et al., 2007) and it is also likely that *Pomacea* will predate directly on amphibian eggs. It has, however, been found that the presence of predatory fish reduces amphibian diversity (Hecnar and M'Closkey, 1997) and that reductions in phytophilic, predatory fish at lower macrophyte abundance may have some secondary positive effects on amphibian diversity. The histogram below (Figure 23) indicates that increasing snail biomass has a quite serious impact on amphibian biodiversity in both the short and long term.

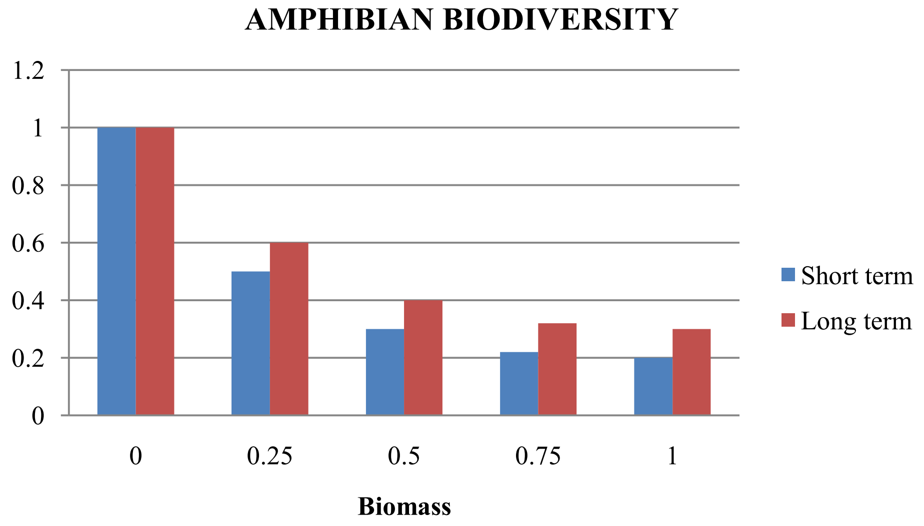


Figure 23: Change in the amphibian biodiversity due to the effect of snail biomass. The y-axis shows the value of the variable *ET* in the short and long term, as estimated by experts, for the levels 0 (no snails), 0.25, 0.5, 0.75 and 1 of the realised biomass normalised to 1 (on the x-axis).

4.2.3.3. Fish biodiversity

Several fish species consume macrophytes, and even more fish species consume macroinvertebrates at some life stage. Reductions in macrophytes, macroinvertebrates and visibility (as a result of a shift from macrophyte to phytoplankton dominance) reduce the feeding success of fish species that consume macrophytes or macroinvertebrates or which use their vision to catch mobile prey. Perhaps more important is the fact that the loss of macrophytes constitutes a loss of spawning substrate for many fish species. It has previously been demonstrated that the reductions in macrophyte abundance and macrophyte species diversity that have resulted from eutrophication have induced large shifts in European fish communities (Wolter et al., 2000). All phytophilic (macrophyte dependent) fish species, for example pike (*Esox lucius* L.), common carp (*Cyprinus carpio* L.) and tench (*Tinca tinca* L.), have declined greatly while other more generalistic and less macrophyte-dependent species, such as pikeperch (*Stizostedion lucioperca* L.), are becoming increasingly abundant (Wolter et al., 2000). Even in areas where the chemical water quality has improved markedly in recent decades after the implementation of large-scale nutrient retention programmes, the recovery of phytophilic fish species is slow owing to the weak recolonisation potential of macrophyte communities in turbid waters (Aarts et al., 2004). If herbivorous *Pomacea* snails enter such an ecosystem, macrophyte abundance, macrophyte diversity and macrophyte recovery are further and negatively affected. These negative effects may be very pronounced, even in larger lakes and rivers where the macrophytes are present only in a small shallow fraction of the littoral zone since many fish species migrate to, and spawn in, the macrophyte beds in the shallows in spring. Loss of spawning substrate may then affect the fish community in the entire lake or river. Intense phytoplankton production may raise the pH of the water to toxic levels that lead to fish mortality; lowered oxygen concentrations may also negatively affect fish species with high oxygen demands. Since most fish species are long-lived, the negative effect on fish species diversity is expected to increase in the long term. The histogram below (Figure 24) indicates that increasing snail biomass has a moderate impact on fish biodiversity in the short term and higher impact in the long term.

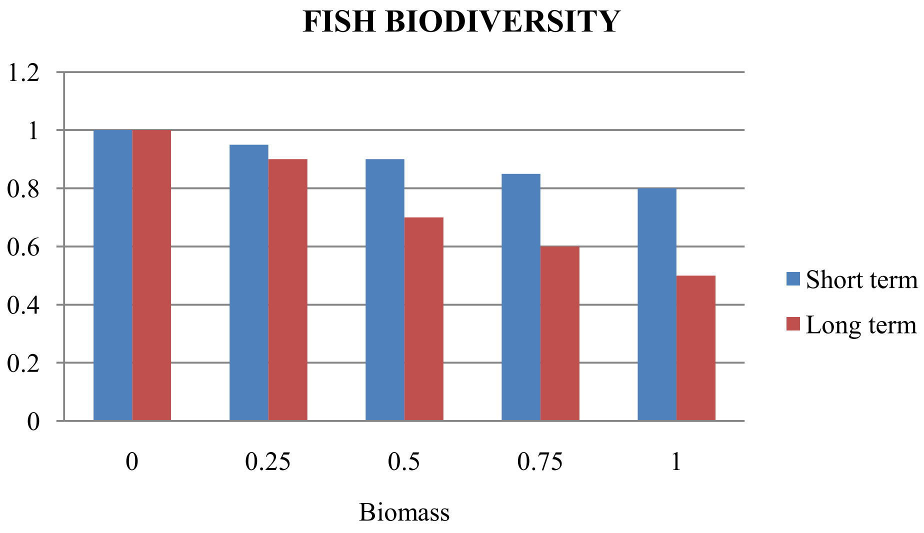


Figure 24: Change in the fish biodiversity due to the effect of snail biomass. The y-axis shows the value of the variable *ET* in the short and long term, as estimated by experts, for the levels 0 (no snails), 0.25, 0.5, 0.75 and 1 of the realised biomass normalised to 1 (on the x-axis).

4.2.3.4. Bird biodiversity

Depending on the bird species, reduction in aquatic plant biomass, reduction in macroinvertebrates and reduction in fish or amphibian biomass and species all represent reductions in food availability for birds. Macrophytes are essential food for many bird species in Europe (Rodríguez-Villafañe et al., 2007). If the clarity of the water is reduced because it becomes phytoplankton dominated rather than macrophyte dominated, the hunting success of birds that use their vision to hunt (for example, kingfisher and osprey) will also be reduced. Birds that learn to effectively use *Pomacea* as a food source may, however, benefit from this increasing food source (Carlsson et al., 2009). Since most bird species are long-lived, the negative effect on bird species diversity is expected to increase in the long term. The histogram below (Figure 25) indicates that increasing snail biomass has a moderate impact on bird biodiversity in the short term and a higher impact in the long term.

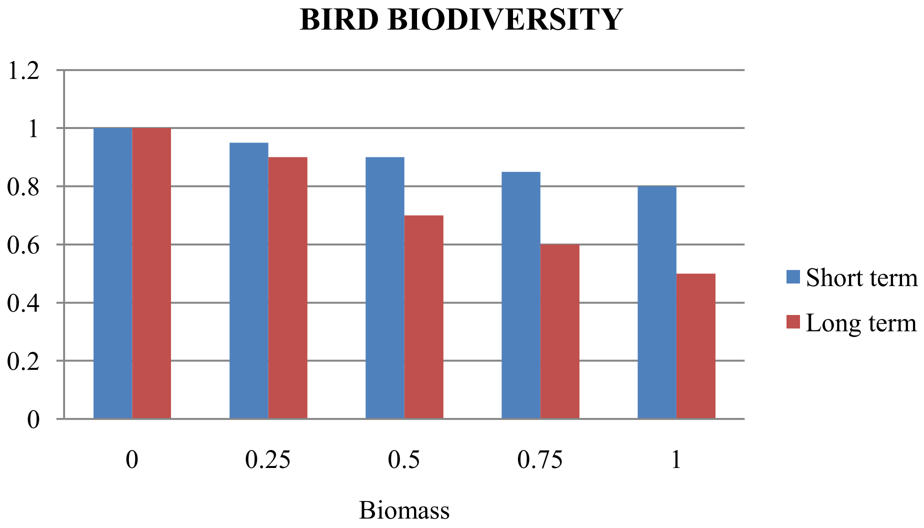


Figure 25: Change in the bird biodiversity due to the effect of snail biomass. The y-axis shows the value of the variable *ET* in the short and long term, as estimated by experts, for the levels 0 (no snails), 0.25, 0.5, 0.75 and 1 of the realised biomass normalised to 1 (on the x-axis).

4.2.3.5. Zooplankton biodiversity

Macrophytes are a very important refuge for zooplankton, and several species are expected to disappear by predation when macrophytes decline. Intense phytoplankton production may raise the pH of the water to toxic levels which will kill zooplankton. The histogram below (Figure 26) indicates that increasing snail biomass has a serious impact on zooplankton biodiversity in the short term, and a less serious effect in the long term.

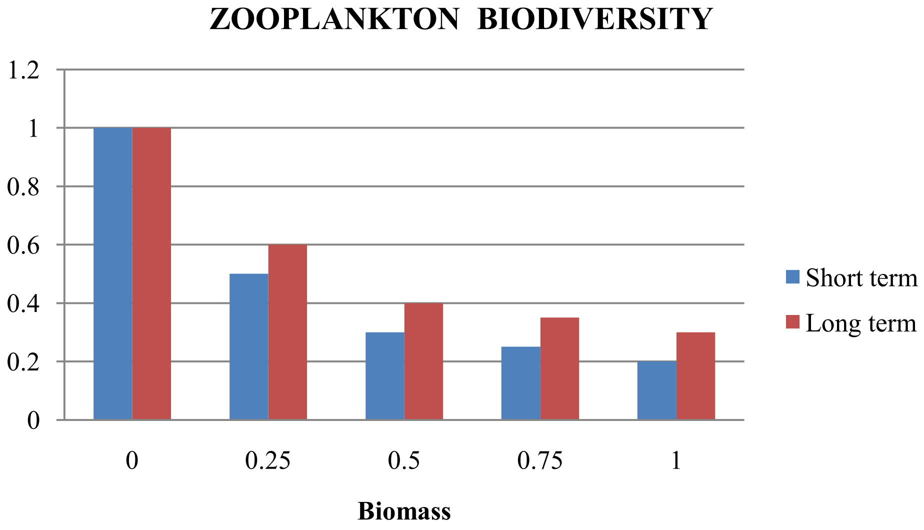


Figure 26: Change in the zooplankton biodiversity due to the effect of snail biomass. The y-axis shows the value of the variable *ET* in the short and long term, as estimated by experts, for the levels 0 (no snails), 0.25, 0.5, 0.75 and 1 of the realised biomass normalised to 1 (on the x-axis).

4.2.3.6. Zooplankton biomass

Macrophytes are a very important refuge for zooplankton, and several species are expected to disappear by predation when macrophytes decline. Intense phytoplankton production may raise the pH of the water to toxic levels that kills zooplankton. The histogram below (Figure 27) indicates that increasing snail biomass has a serious impact on zooplankton biomass in the short term while the effect is less serious in the long term.

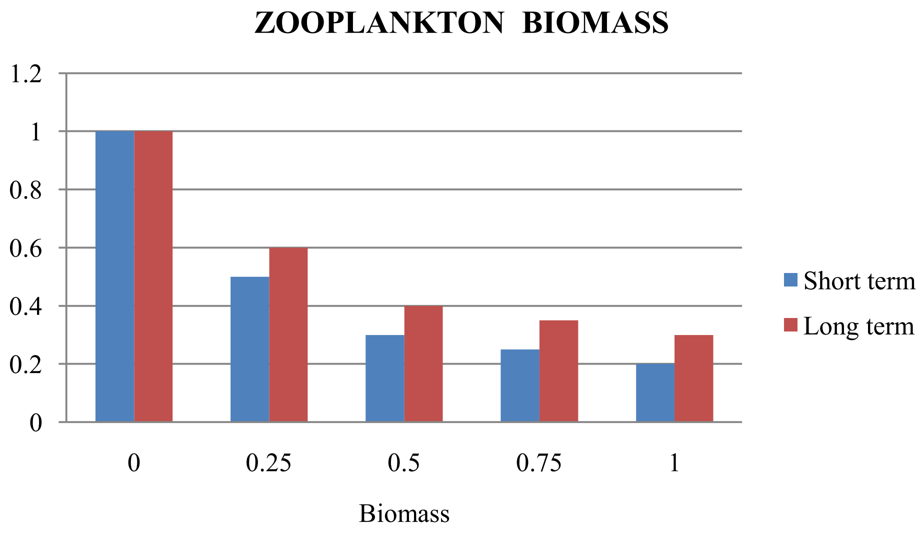


Figure 27: Change in the zooplankton biomass due to the effect of snail biomass. The y-axis is reported the value of the variable *ET* in the short and long term, as estimated by experts, for the levels 0 (no snails), 0.25, 0.5, 0.75 and 1 of the realised biomass normalised to 1 (on the x-axis).

4.2.3.7. Periphyton biomass

Periphyton utilise macrophytes as substrate for growth. Reduced substrate leads to reduced periphyton biomass. The histogram below (Figure 28) indicates that increasing snail biomass has a very serious impact on periphyton biomass in both the short and the long term.

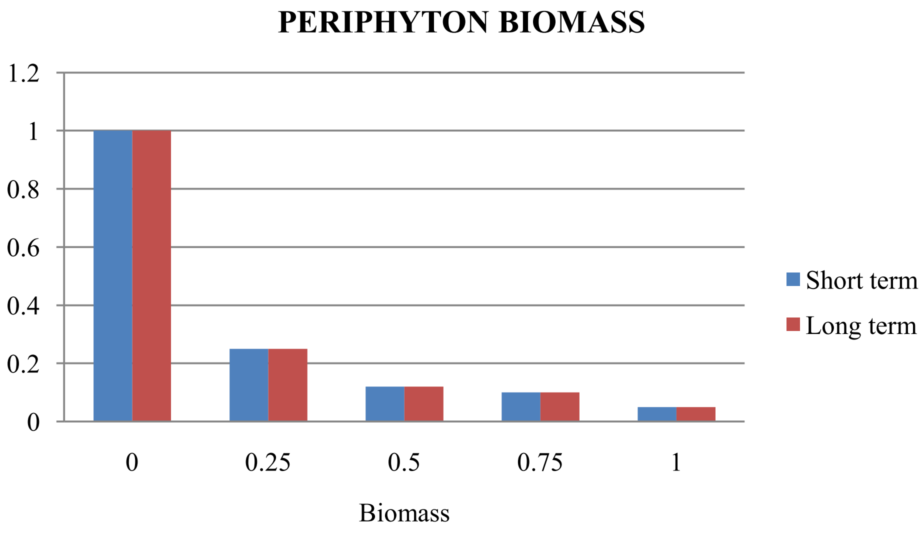


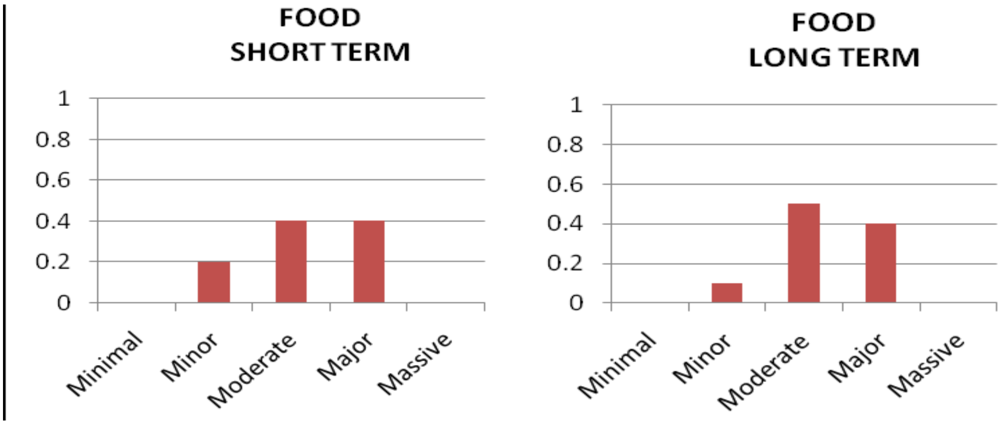
Figure 28: Change in the periphyton biomass due to the effect of snail biomass. The y-shows the value of the variable *ET* in the short and long term, as estimated by experts, for the levels 0 (no snails), 0.25, 0.5, 0.75 and 1 of the realised biomass normalised to 1 (on the x-axis).

4.3. Effect on ecosystem services

4.3.1. Provisioning service

4.3.1.1. Food

The expected effects of increased snail biomass on food production (reduction in fish biomass and waterfowl biomass, increase in toxic algae negatively affecting aquaculture and livestock production) are moderate to major, both in the short term and in the long term, and are rated with medium uncertainty. The reduction is predicted to increase somewhat in the long term since many fish and bird species are long-lived and the effect on recruitment should therefore be more pronounced than the effects on individuals. Difficulties in predicting increases in macrophytes species non-palatable to *Pomacea* (i.e. those species with high contents of phenolic compounds and relatively low contents of nutrients (low C/N ratio)) that may offer some compensation for the loss of palatable macrophytes add uncertainty to the predictions.

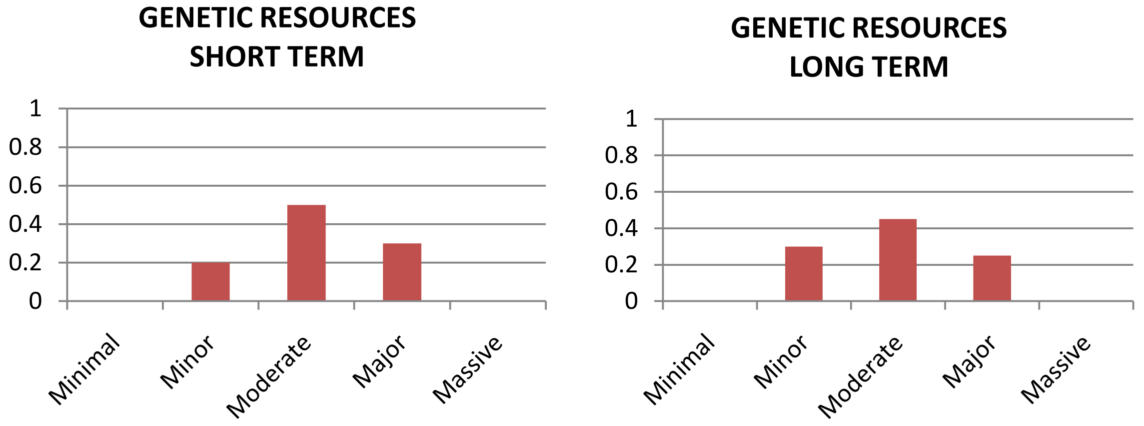


	Minimal	Minor	Moderate	Major	Massive	Uncertainty
Short term	0	0.2	0.4	0.4	0	0.655
Long term	0	0.1	0.5	0.4	0	0.586

Figure 29: Probability distribution and associated uncertainty of the reduction in the provision level of the ecosystem service ‘food’. The expert estimates were performed based on the worst-case scenario (maximum realised snail biomass) in the short and long term.

4.3.1.2. Genetic resources

The reduction in genetic resources occurring in and nearby wetlands due to *Pomacea* are expected to range from minor to major in both the short and long term. The uncertainties for these predictions are medium and relate to difficulties in predicting the future development and presence of certain macrophytes and species able to live in habitats created by these macrophytes.

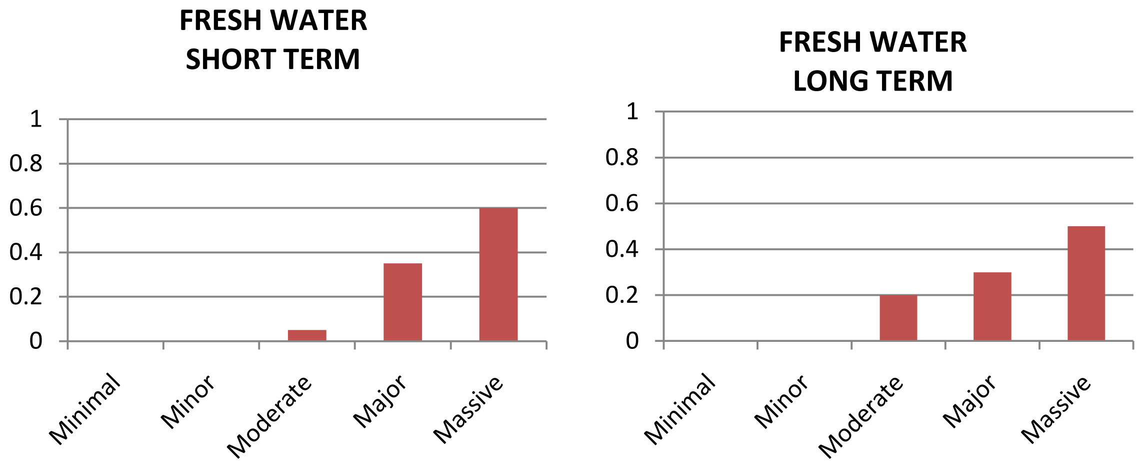


	Minimal	Minor	Moderate	Major	Massive	Uncertainty
Short term	0	0.2	0.5	0.3	0	0.640
Long term	0	0.3	0.45	0.25	0	0.663

Figure 30: Probability distribution and associated uncertainty of the reduction in the provision level of the ecosystem service ‘genetic resources’. The expert estimates were performed based on the worst-case scenario (maximum realised snail biomass) in the short and long term.

4.3.1.3. Fresh water

The effects of *Pomacea* on water quantity in wetlands are not expected to be very important, but the reduction in water quality (due to increased turbidity and pollution) is expected to be massive both in the short term and in the long term since the loss of macrophytes and the expected shift towards phytoplankton dominance drastically reduces the water purification potential of the system. The uncertainty of these ratings is in the medium range and relates to difficulties in predicting the possible long-term increase in non-palatable macrophytes that may offer some compensation for the loss of palatable macrophytes. Unfortunately, as mentioned earlier, eutrophication is an ongoing process and *Pomacea* not only accelerate this ongoing degradation of the aquatic ecosystems but also make this undesirable shift less reversible as polyphagous *Pomacea* snails are able to cope with these environmental changes and to maintain high densities thereafter.



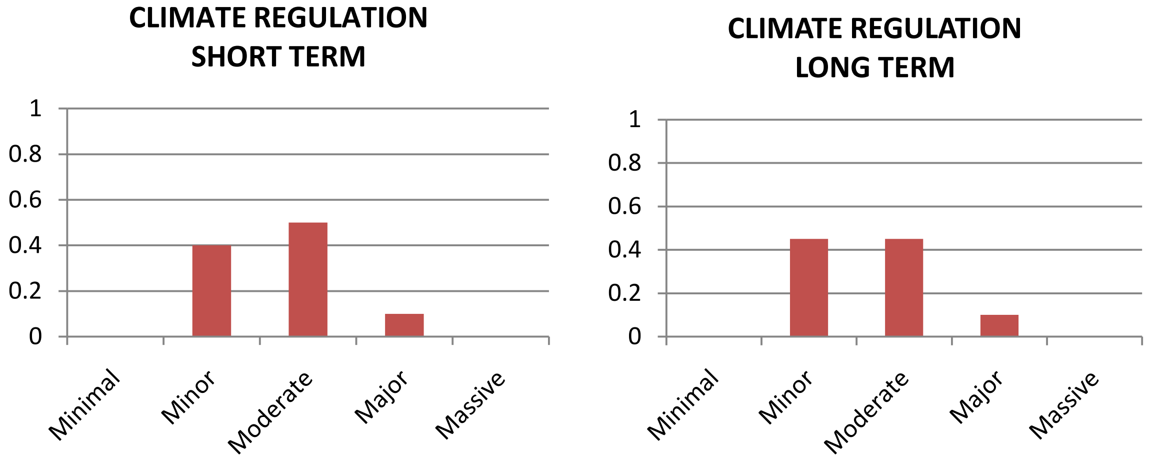
	Minimal	Minor	Moderate	Major	Massive	Uncertainty
Short term	0	0	0.05	0.35	0.6	0.512
Long term	0	0	0.2	0.3	0.5	0.640

Figure 31: Probability distribution and associated uncertainty of the reduction in the provision level of the ecosystem service ‘fresh water’. The expert estimates were performed based on the worst-case scenario (maximum realised snail biomass) in the short and long term.

4.3.2. Regulating and supporting service

4.3.2.1. Climate regulation

The effects of *Pomacea* on climate regulation in the short and long term are concentrated in the moderate/minor range with a medium level of uncertainty. The predictions of the net effects on climate regulation are complicated by the fact that wetlands and lakes are both sinks (through carbon assimilation and retention) and sources (through methane release) of gases that affect climate regulation. The net effect on climate regulation is determined not only by macrophytes but also by many other factors.

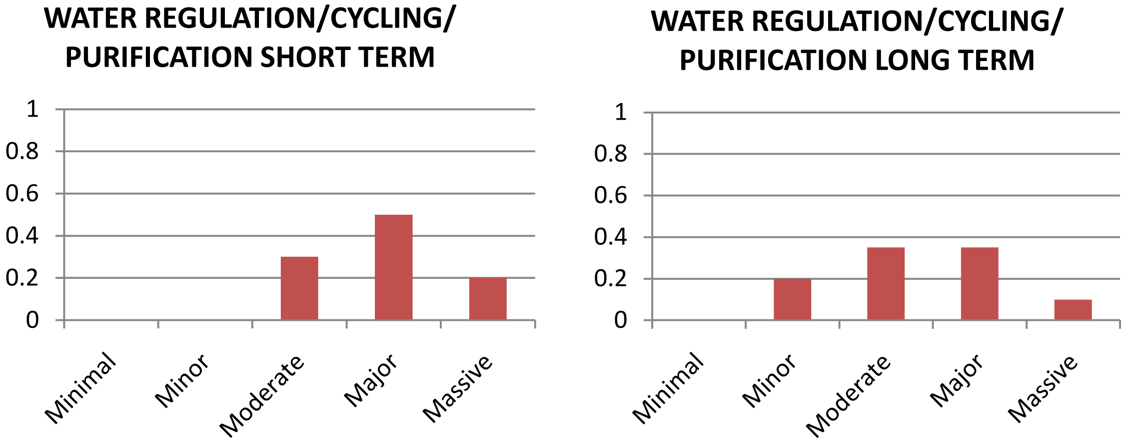


	Minimal	Minor	Moderate	Major	Massive	Uncertainty
Short term	0	0.4	0.5	0.1	0	0.586
Long term	0	0.45	0.45	0.1	0	0.590

Figure 32: Probability distribution and associated uncertainty of the reduction in the provision level of the ecosystem service 'climate regulation'. The expert estimates were performed based on the worst-case scenario (maximum realised snail biomass) in the short and long term.

4.3.2.2. Water regulation/cycling/purification

The effects of *Pomacea* on water runoff, flooding and aquifer recharge are expected to be less important than the effects on the ecosystem's capacity to filter and purify chemical waste through phyto-remediation as well as pathogens and organic pollution. In the short term the Panel expects a major reduction in these purification processes with a medium level of uncertainty. In the long term, a less dramatic reduction (moderate to major) is predicted since an increase in non-palatable macrophytes may offer some compensation for the loss of palatable macrophytes. The uncertainty for this prediction is, however, high, since the expected shift towards phytoplankton dominance may hamper an increase in the non-palatable macrophytes.

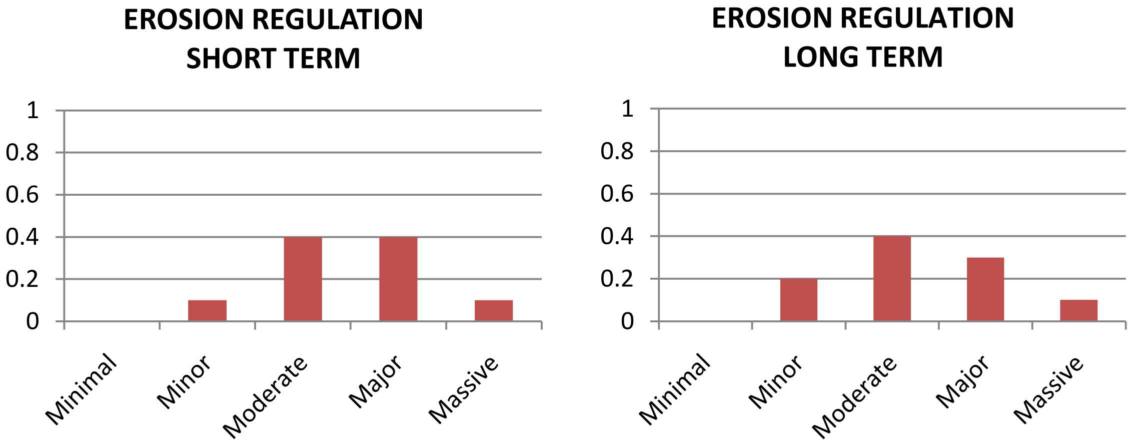


	Minimal	Minor	Moderate	Major	Massive	Uncertainty
Short term	0	0	0.3	0.5	0.2	0.640
Long term	0	0.2	0.35	0.35	0.1	0.800

Figure 33: Probability distribution and associated uncertainty of the reduction in the provision level of the ecosystem service ‘water regulation/cycling/purification’. The expert estimates were performed based on the worst-case scenario (maximum realised snail biomass) in the short and long term.

4.3.2.3. Erosion regulation

The reduction in erosion regulation as a result of *Pomacea* is expected to be between moderate and major in the short term and slightly more moderate than major in the long term since an increase in non-palatable macrophytes may offer some compensation for the loss of root area in palatable macrophytes. However, the uncertainty of these predictions is high. Root area is important in erosion regulation, but erosion is also influenced by many other factors.

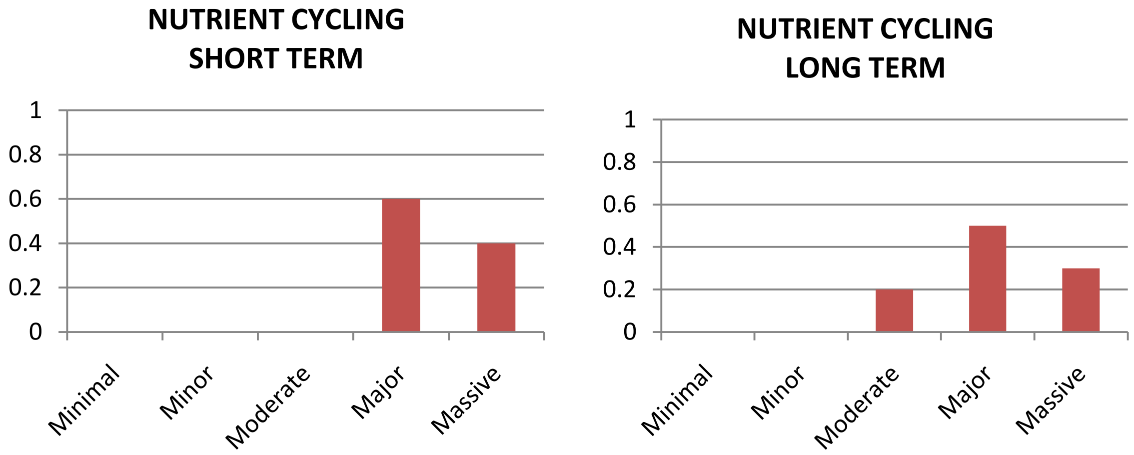


	Minimal	Minor	Moderate	Major	Massive	Uncertainty
Short term	0	0.1	0.4	0.4	0.1	0.742
Long term	0	0.2	0.4	0.3	0.1	0.795

Figure 34: Probability distribution and associated uncertainty of the reduction in the provision level of the ecosystem service ‘erosion regulation’. The expert estimates were performed based on the worst-case scenario (maximum realised snail biomass) for in short and long term.

4.3.2.4. Nutrient cycling

The effects of *Pomacea* on nutrient cycling are predicted to be major to massive in the short term with medium uncertainty. A shift from macrophyte to phytoplankton dominance reduces nutrient burial in the sediments, may induce anoxia at the sediment surface, with subsequent release of phosphorus, and may increase resuspension of sediments. This may cause a release of large quantities of phosphorus and nitrogen to downstream aquatic ecosystems, causing increased eutrophication and coastal hypoxia. In the long term the Panel still expects a major effect with medium uncertainty on nutrient cycling but again an increase of non-palatable macrophytes could offer some compensation for the loss of palatable macrophytes.

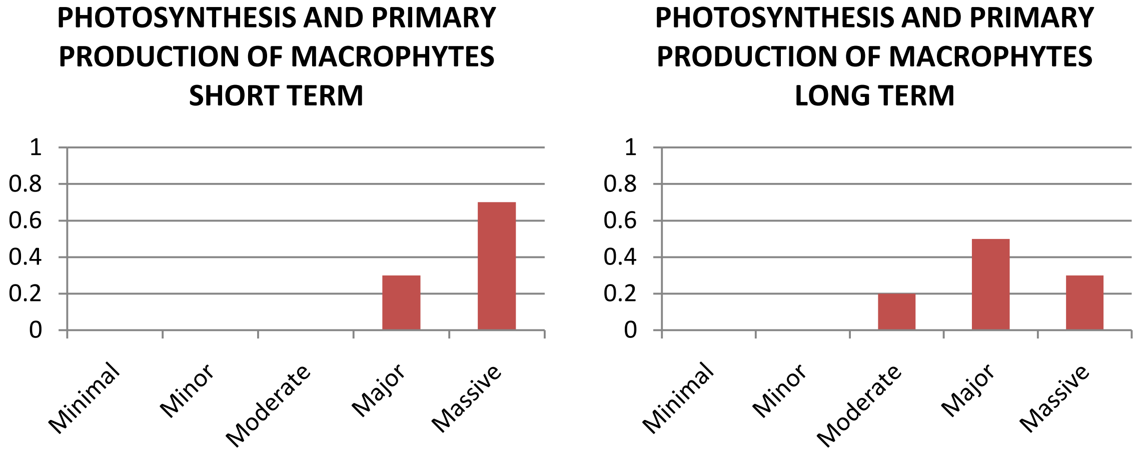


	Minimal	Minor	Moderate	Major	Massive	Uncertainty
Short term	0	0	0	0.6	0.4	0.418
Long term	0	0	0.2	0.5	0.3	0.640

Figure 35: Probability distribution and associated uncertainty of the reduction in the provision level of the ecosystem service 'nutrient cycling'. The expert estimates were performed based on the worst-case scenario (maximum realised snail biomass) in the short and long term.

4.3.2.5. Photosynthesis and primary production of macrophytes

The reduction in primary production and photosynthesis by macrophytes due to *Pomacea* is predicted to be massive in the short term and major in the long term (since some non-palatable macrophyte species may increase), both rated with medium uncertainty.

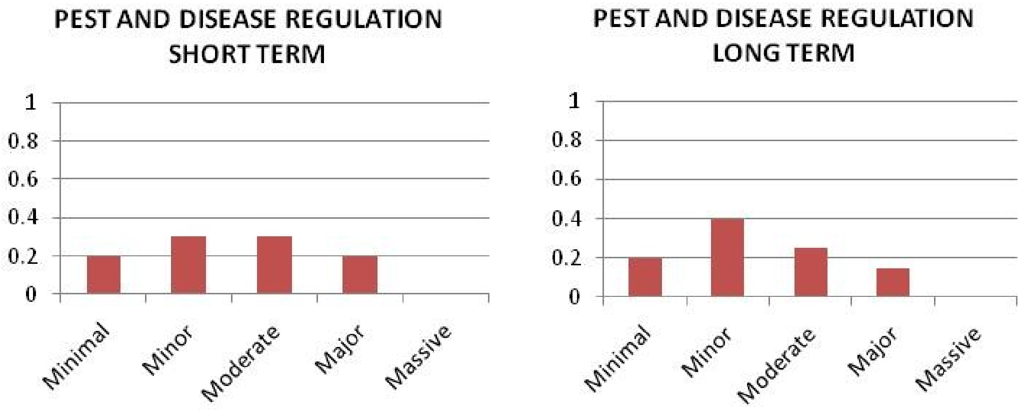


	Minimal	Minor	Moderate	Major	Massive	Uncertainty
Short term	0	0	0	0.3	0.7	0.380
Long term	0	0	0.2	0.5	0.3	0.640

Figure 36: Probability distribution and associated uncertainty of the reduction in the provision level of the ecosystem service ‘photosynthesis and primary production of macrophytes’. The expert estimates were performed based on the worst-case scenario (maximum realised snail biomass) in the short and long term.

4.3.2.6. Pest and disease regulation

There is high uncertainty about the predictions of reductions in pest and disease regulation due to *Pomacea*. Reduced water quality may interfere with the natural reduction of waterborne pathogens and diseases, and induce toxic phytoplankton production with far-reaching consequences for many organisms. *Pomacea* spp. may also be an intermediate host for the rat lung worm (*Angiostrongylus cantonensis*; endemic in regions such as Southeast Asia, China, the Pacific Basin, and the Caribbean, but international travel has spread the disease elsewhere, including some cases of human infections were reported in Europe (Maretić et al., 2009)), which can cause serious illness in many organisms. On the other hand, mosquito production is often higher in habitats that are dominated by macrophytes, and mosquitoes can also be important vectors for several diseases.

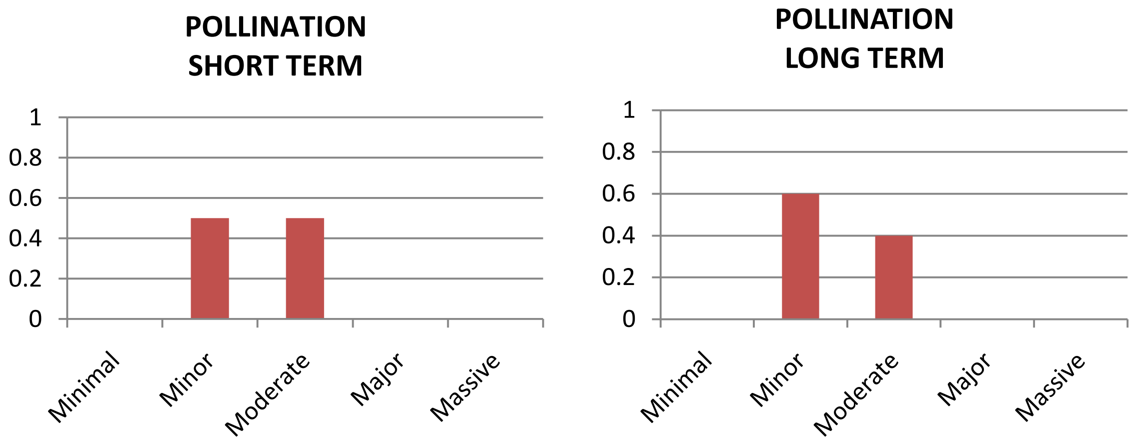


	Minimal	Minor	Moderate	Major	Massive	Uncertainty
Short term	0.2	0.3	0.3	0.2	0	0.849
Long term	0.2	0.4	0.25	0.15	0	0.820

Figure 37: Probability distribution and associated uncertainty of the reduction in the provision level of the ecosystem service 'pest and disease regulation'. The expert estimates were performed based on the worst-case scenario (maximum realised snail biomass) in the short and long term.

4.3.2.7. Pollination

The reduction in native pollinators due to *Pomacea* is predicted to be between minor and moderate in the short term and slightly less in the long term considering the possible increase in non-palatable macrophytes. Both estimates have medium uncertainty. Macrophyte abundance will be reduced, but many macrophyte species are wind pollinated or submerged and not available for pollinators anyway. There will, however, be a reduction also in flowering macrophytes that may have negative effects on pollinators.



	Minimal	Minor	Moderate	Major	Massive	Uncertainty
Short term	0	0.5	0.5	0	0	0.431
Long term	0	0.6	0.4	0	0	0.418

Figure 38: Probability distribution and associated uncertainty of the reduction in the provision level of the ecosystem service 'pollination'. The expert estimates were performed based on the worst-case scenario (maximum realised snail biomass) in the short and long term.

4.4. Effect on biodiversity components

In the assessment of impact of the apple snail on the biodiversity components, the Panel gathered expert judgements and applied the three different approaches used in the previous sections:

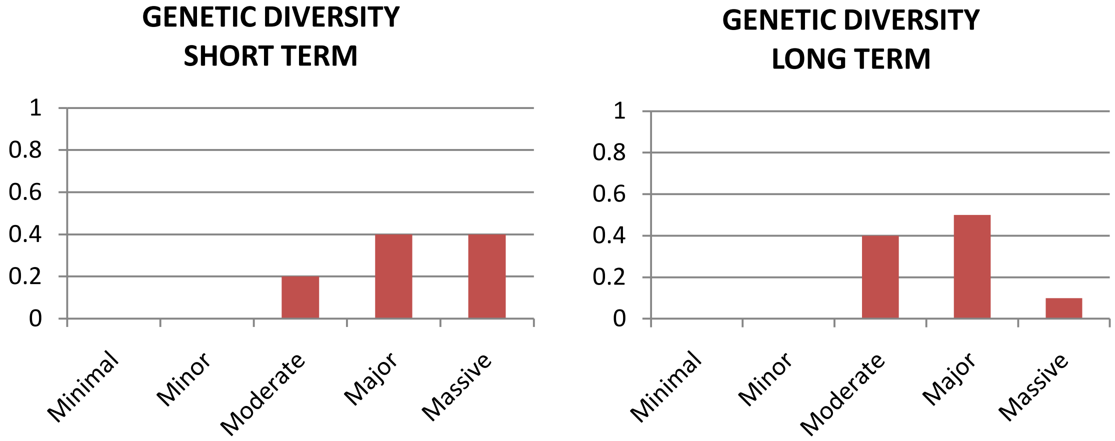
- Histograms of the probability distribution of the reduction in the biodiversity component in the SPU due to snail invasion were compiled. Similarly to the ecosystem services (see Section 4.3), the probability distribution of reduction for different classes of impact allowed the assessment of the risk and the evaluation of the uncertainty.
- Histograms showing the relationship between the biodiversity component and the potential biomass of the snails were compiled.
- Information on the relationship between apple snail biomass and the biodiversity components was used to derive a continuous function allowing maps describing the spatial distribution of the impact according to the realised biomass in each cell of the simulation grid to be generated. As an example, maps have been developed for threatened species, for habitats of high conservation value and native habitats and for community and/or ecosystem diversity in the SPU.

As a result, different levels of resolution of the ERA are presented in this chapter. The possibility of developing one approach separately or in combination with the other two approaches demonstrates the flexibility of the ERA, considering that the assessment scheme can be adapted to the knowledge available.

4.4.1. Genetic diversity

The reduction in genetic diversity due to *Pomacea* is predicted to be major to massive in the short term and major in the long term with medium uncertainty. The reduction in density of several macrophyte populations constitutes a direct loss of genetic diversity, whilst secondary reductions in genetic diversity stem from reductions of population density of several groups of organisms that depend on macrophytes at any life stage. In the long term the aquatic habitats may be recolonised by non-palatable macrophytes and some recovery of organisms that depends on macrophytes may occur.

- In the worst-case scenario



	Minimal	Minor	Moderate	Major	Massive	Uncertainty
Short term	0	0	0.2	0.4	0.4	0.655
Long term	0	0	0.4	0.5	0.1	0.586

Figure 39: Probability distribution and associated uncertainty of the reduction in genetic diversity. The expert estimates were performed based on the worst-case scenario (maximum realised snail biomass) in the short and long term.

- Effect of snail biomass on the genetic diversity

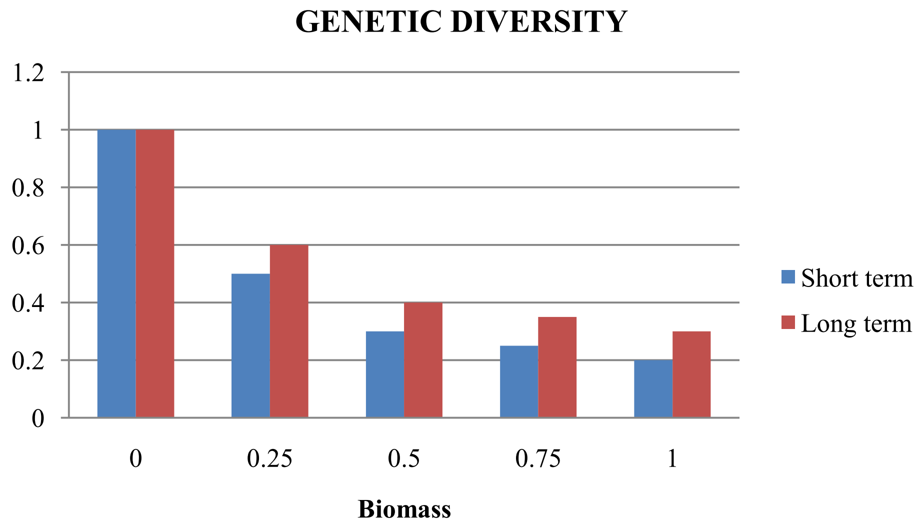
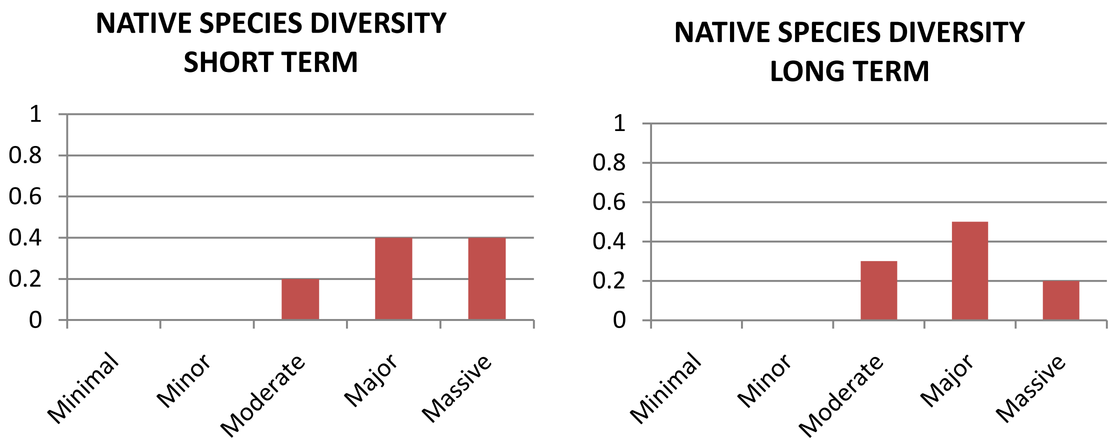


Figure 40: Change in the genetic diversity due to the effect of snail biomass. The y-axis shows the value of the variable *ET* in the short and long term, as estimated by experts, for the levels 0 (no snails), 0.25, 0.5, 0.75 and 1 of the realised biomass normalised to 1 (on the x-axis).

4.4.2. Native species diversity

The reduction in native species diversity due to *Pomacea* is predicted to be major to massive in the short term and major in the long term with medium uncertainty. Some macrophyte species may be lost from the system, resulting in further loss of native species that depend on macrophytes. In the long term the aquatic habitats may be recolonised by non-palatable macrophytes and some recovery of native organisms that depend on these may occur.

- In the worst-case scenario



	Minimal	Minor	Moderate	Major	Massive	Uncertainty
Short term	0	0	0.2	0.4	0.4	0.655
Long term	0	0	0.3	0.5	0.2	0.640

Figure 41: Probability distribution and associated uncertainty of the reduction in native species diversity. The expert estimates were performed based on the worst-case scenario (maximum realised snail biomass) in the short and long term.

- Effect of snail biomass on the biodiversity of native species

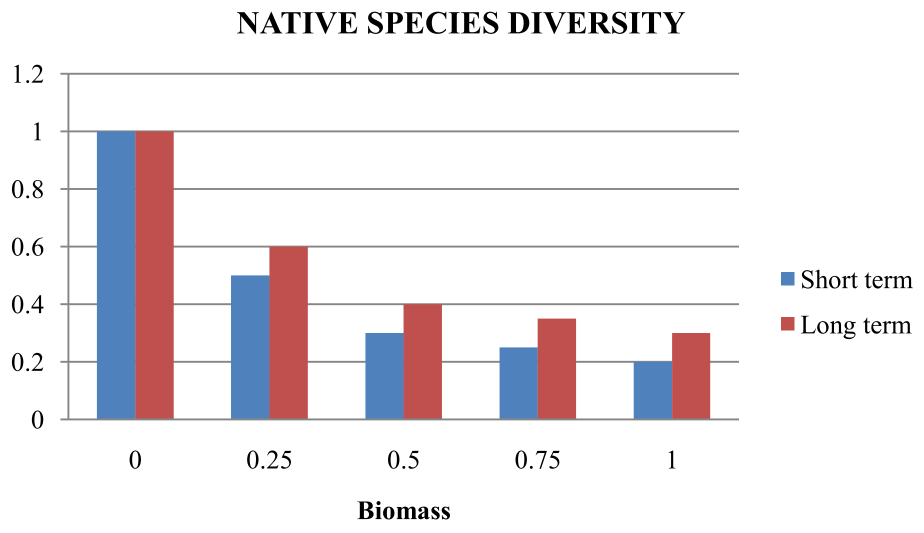


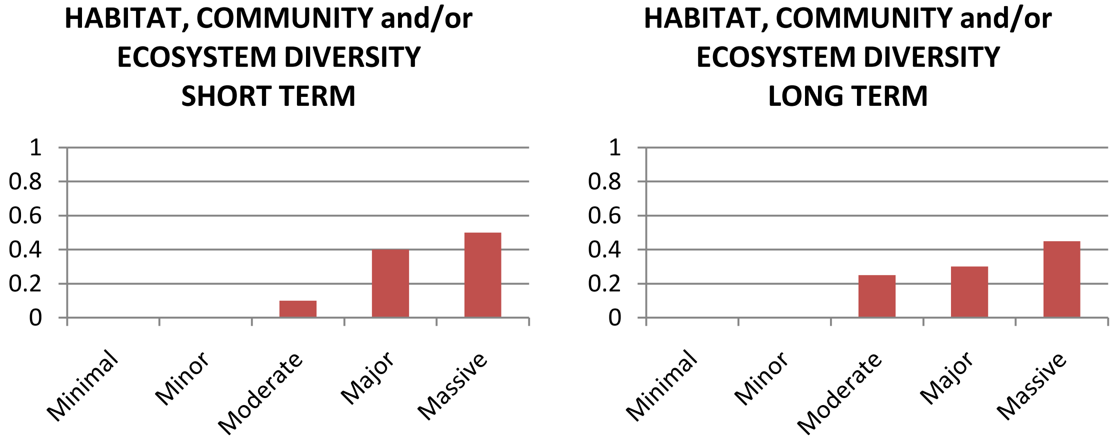
Figure 42: Change in the native species diversity due to the effect of snail biomass. The y-axis shows the value of the variable *ET* in the short and long term, as estimated by experts, for the levels 0 (no snails), 0.25, 0.5, 0.75 and 1 of the realised biomass normalised to 1 (on the x-axis).

4.4.3. Habitat, community and/or ecosystem diversity

The reduction in the composition and structure of the habitats, compared with the pre-invasion stage without *Pomacea*, will be massive in both the short and long term in the worst-case scenario, with medium uncertainty. The long-term reduction may be less drastic since some macrophytes resistant to *Pomacea* grazing may recolonise. When the macrophytes, constituting the varied and structurally complex habitats, disappear, the entire ecosystem changes, with far-reaching effects on all organisms at both the individual and community levels.

The realised biomass is, however, significantly lower in the long term and different from the worst-case scenario. Based on the realised biomass in the long and the short term in Figure 45a and b the Panel can conclude that, in the short term, the impact of snail biomass on habitat diversity is quite serious in a large part of the Mediterranean area, and in the long term is slightly less serious.

- In the worst-case scenario



	Minimal	Minor	Moderate	Major	Massive	Uncertainty
Short term	0	0	0.1	0.4	0.5	0.586
Long term	0	0	0.25	0.3	0.45	0.663

Figure 43: Probability distribution and associated uncertainty of the reduction in habitat, community and/or ecosystem diversity. The expert estimates were performed based on the worst-case scenario (maximum realised snail biomass) in the short and long term.

- Effect of snail biomass on the habitat, community and/or ecosystem diversity

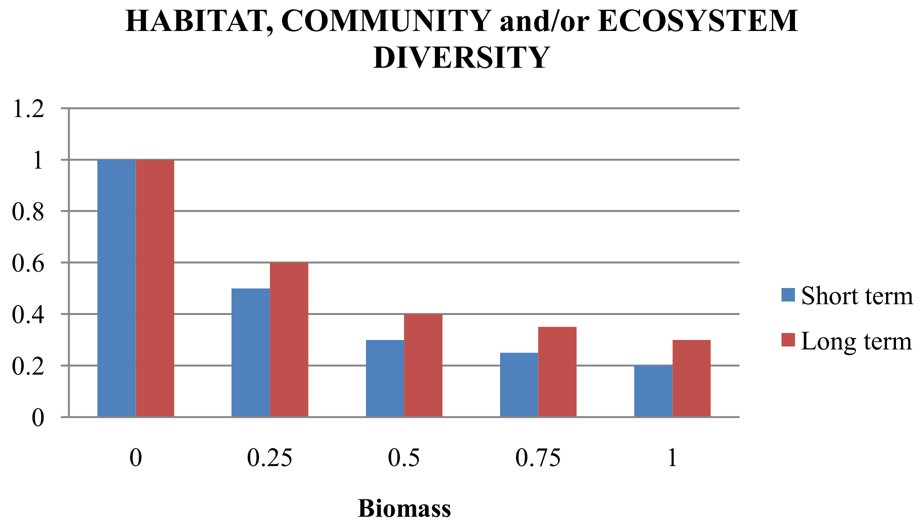
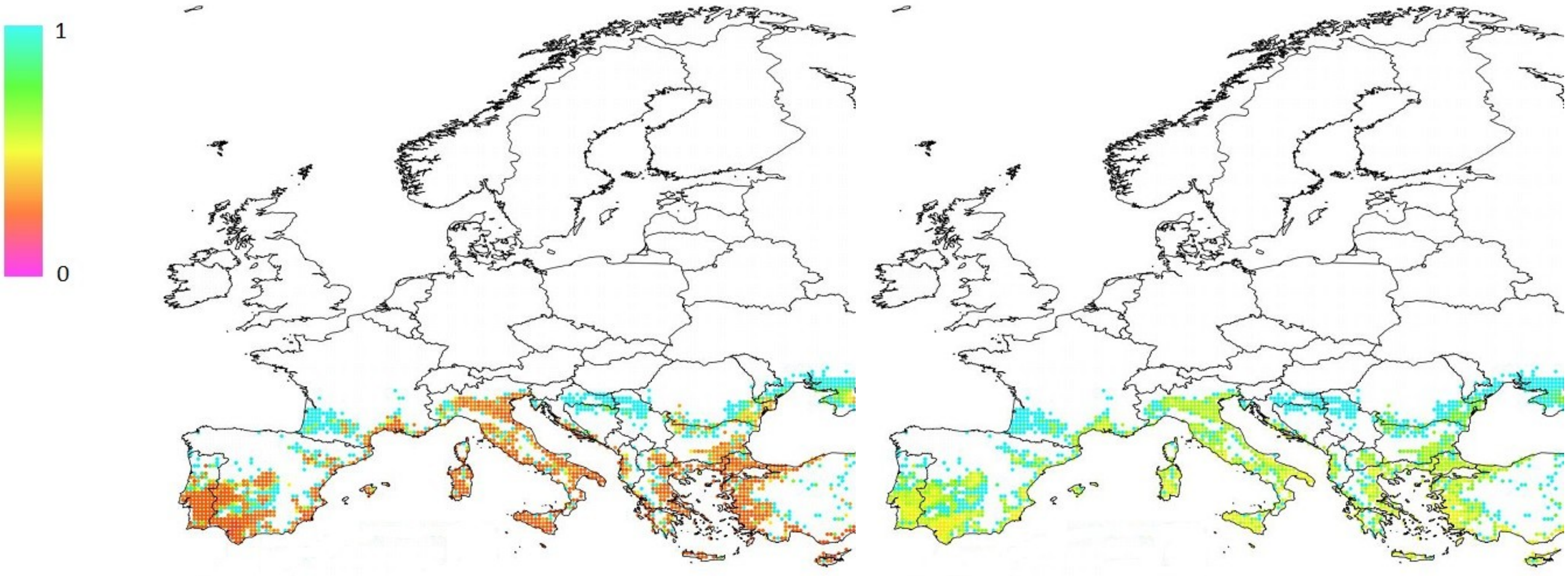


Figure 44: Change in the habitat, community and/or ecosystem diversity due to the effect of snail biomass. The y-axis shows reported the value of the variable *ET* in the short and long term, as estimated by experts, for the levels 0 (no snails), 0.25, 0.5, 0.75 and 1 of the realised biomass normalised to 1 (on the x-axis).

- Spatial distribution of the impact



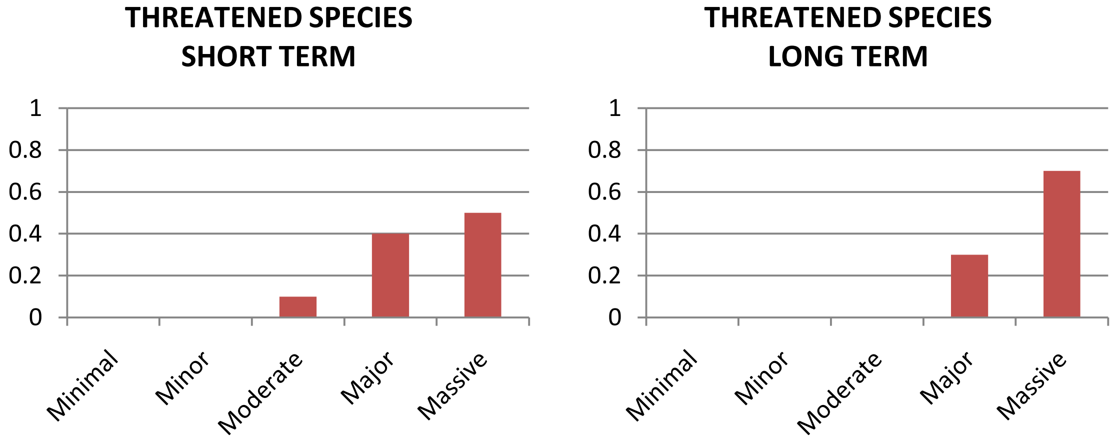
a. 5 years **b. 30 years**

Figure 45: Distribution of the index I_{ET} representing the change in the habitat diversity due to the effects of the realised snail biomass in the two time horizons. Values of the index close to zero correspond to high impact on the ecosystem trait; values of the index close to 1 denote a low impact: (a) 5 years, short term; (b) 30 years, long term.

4.4.4. Threatened species

The reduction in threatened species due to a *Pomacea* invasion is predicted to be massive in both the short and the long term with medium uncertainty. Threatened species exist in small numbers at a few places and a reduction mediated through an ecosystem change will have drastic effects on their persistence. Further, many threatened species require environmental conditions that are becoming scarce such as clear, oligotrophic water and an undisturbed ecosystem. In the worst-case scenario, reductions would be even more pronounced in the long term since many threatened species are long lived and some of the effects of reduced recruitment become apparent only in the long term. The realised biomass is, however, much lower in the long term and different from the worst-case scenario. Based on the realised biomass in the two time dimensions in Figure 48a and b, the Panel can conclude that, in the short term, the impact of the realised snail biomass on threatened species is very serious in a large part of the Mediterranean area, and that in the long term the effect is serious.

- In the worst-case scenario



	Minimal	Minor	Moderate	Major	Massive	Uncertainty
Short term	0	0	0.1	0.4	0.5	0.586
Long term	0	0	0	0.3	0.7	0.380

Figure 46: Probability distribution and associated uncertainty of the reduction in threatened species. The expert estimates were performed based on the worst-case scenario (maximum realised snail biomass) in the short and long term.

- Effect of snail biomass on the threatened species

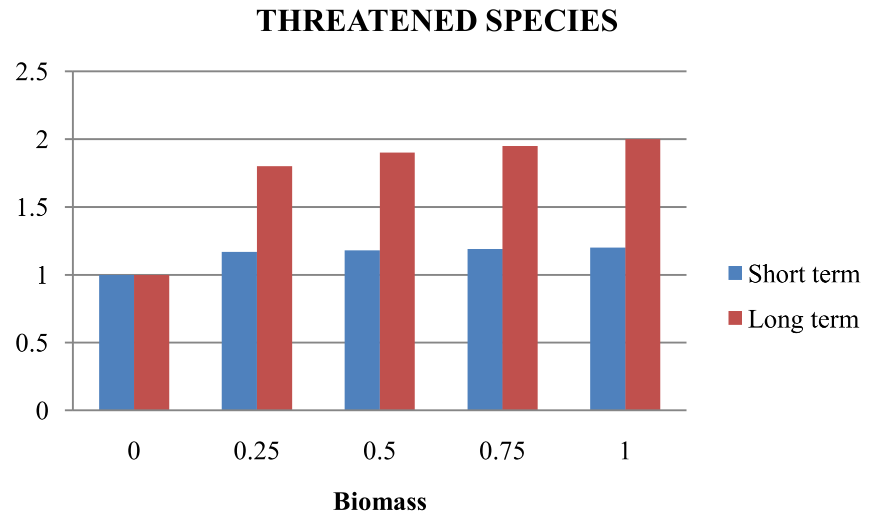
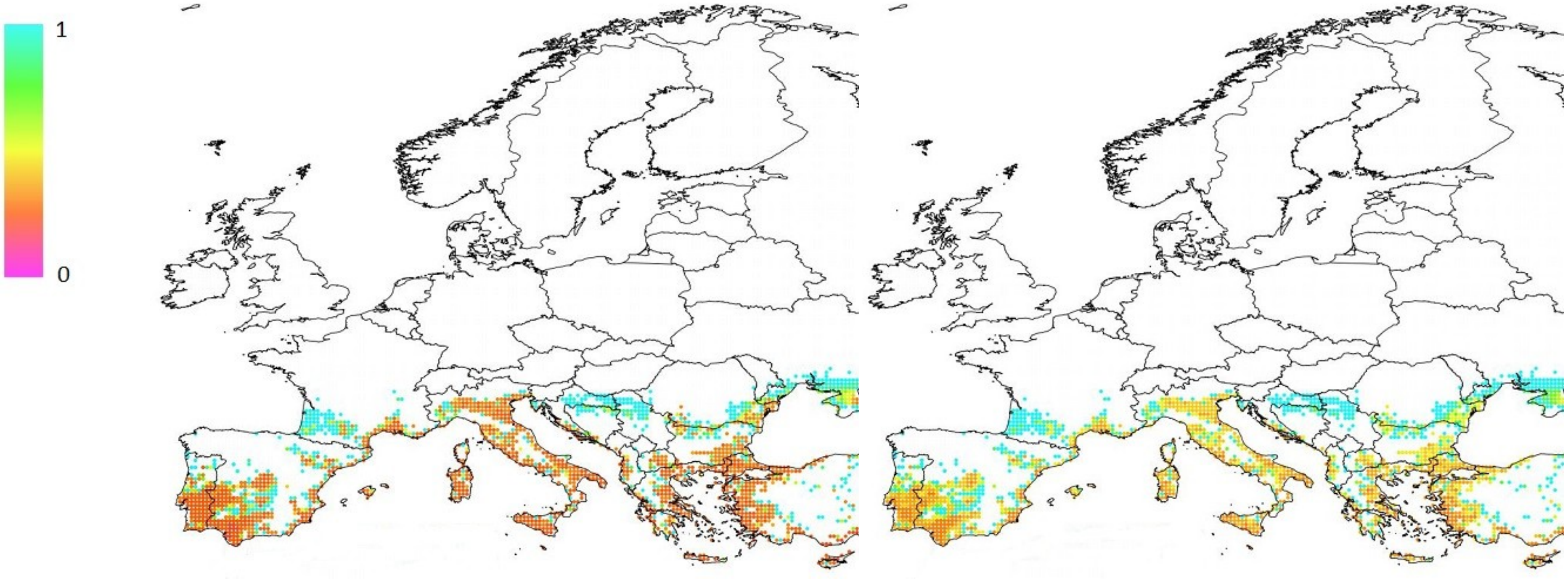


Figure 47: Change in the threatened species due to the effect of snail biomass. The y-axis shows the value of the variable *ET* in the short and long term, as estimated by experts, for the levels 0 (no snails), 0.25, 0.5, 0.75 and 1 of the realised biomass normalised to 1 (on the x-axis).

- Spatial distribution of the impact



a. 5 years **b. 30 years**

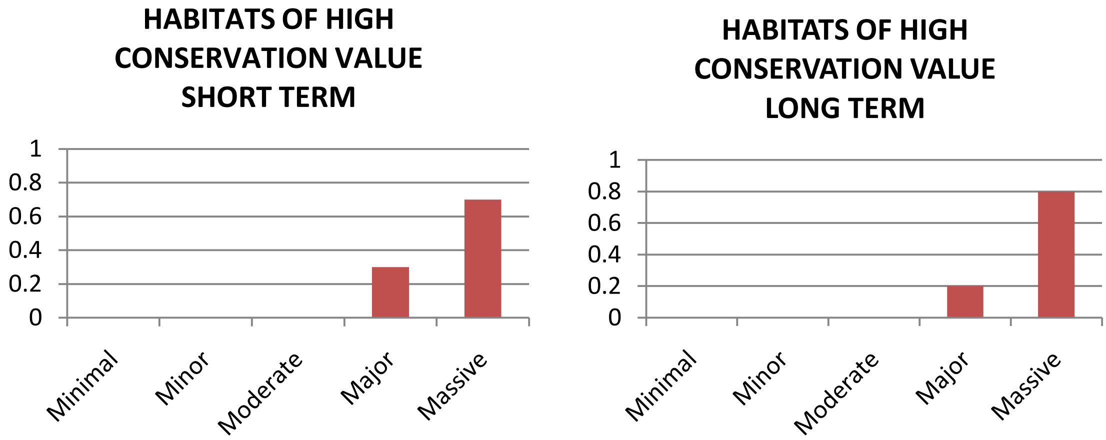
Figure 48: Distribution of the index I_{ET} representing the change in threatened species due to the effects of the realised snail biomass in the two time horizons. Values of the index close to zero correspond to high impact on the ecosystem trait, values of the index close to 1 denote a low impact: (a) 5 years, short term; (b) 30 years, long term.

4.4.5. Habitats of high conservation value

The reduction in habitats of high conservation value due to the presence of *Pomacea* is predicted to be massive in both the short and long term in the worst-case scenario, estimated with medium uncertainty for the short term and low uncertainty for the long term. These high conservation value habitats are particularly sensitive to an invasion of an effective herbivore that changes the structure of the habitats.

The realised biomass is, however, lower in the long term and different from the worst-case scenario. Based on the realised biomass for the short and the long term in Figure 51a and b, the Panel can conclude that the impact on habitats of high conservation value is very serious in a large part of the Mediterranean area in the short term and pronounced also in long term.

- In the worst-case scenario



	Minimal	Minor	Moderate	Major	Massive	Uncertainty
Short term	0	0	0	0.3	0.7	0.380
Long term	0	0	0	0.2	0.8	0.311

Figure 49: Probability distribution and associated uncertainty of the reduction in the habitats of high conservation value. The expert estimates were performed based on the worst-case scenario (maximum realised snail biomass) in the short and long term.

- Effect of snail biomass on the habitats of high conservation value

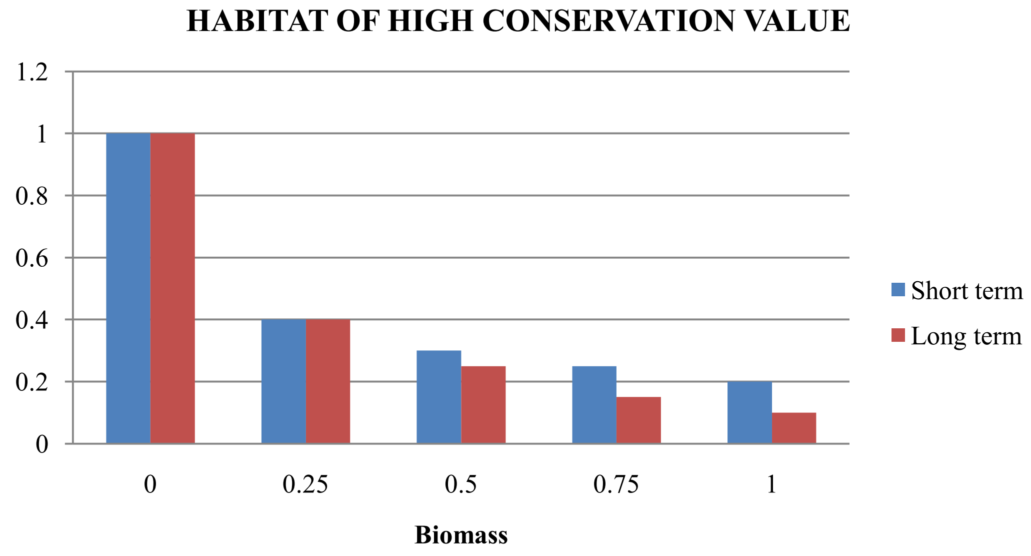
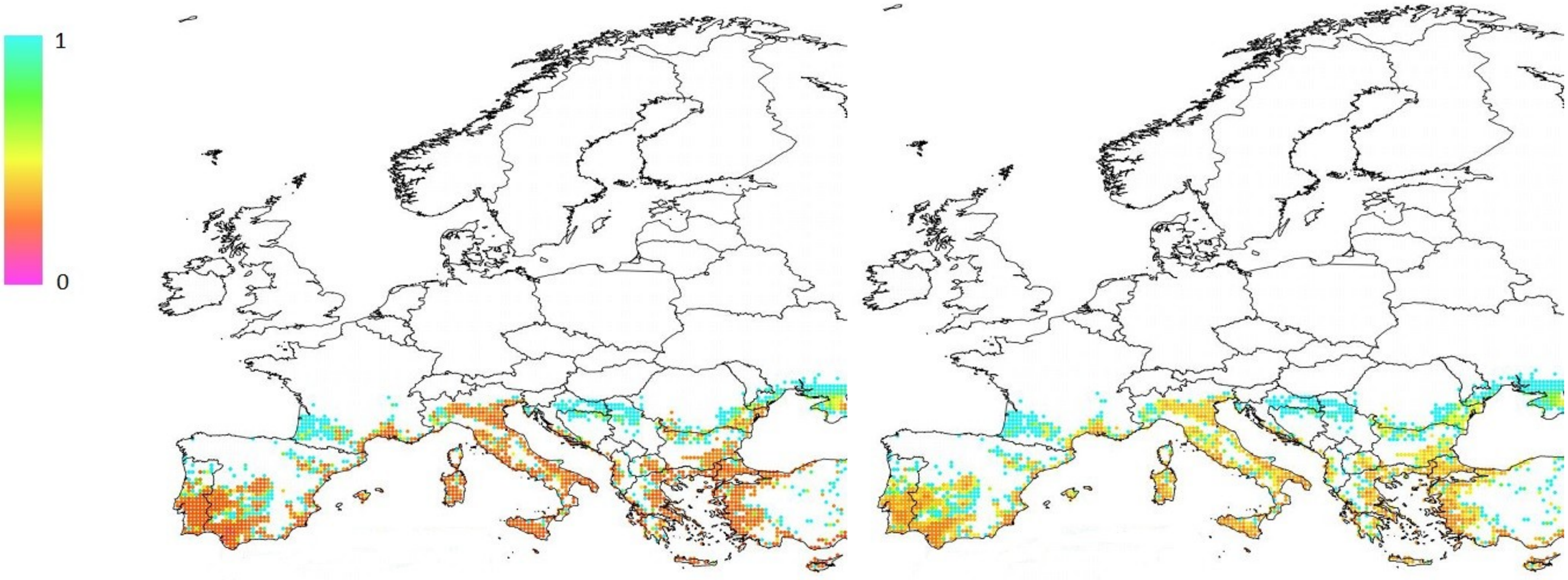


Figure 50: Change in the habitats of high conservation value due to the effect of snail biomass. The y-axis shows the value of the variable *ET* in the short and long term, as estimated by experts, for the levels 0 (no snails), 0.25, 0.5, 0.75 and 1 of the realised biomass normalised to 1 (on the x-axis).

- Spatial distribution of the impact



a. 5 years **b. 30 years**

Figure 51: Distribution of the index I_{ET} representing the change in the habitat of high conservation value due to the effects of the realised snail biomass in the two time horizons. Values of the index close to zero correspond to high impact on the ecosystem trait; values of the index close to 1 denote a low impact: (a) 5 years, short term; (b) 30 years, long term.

4.5. Overall risks and uncertainties

For each ecosystem service and biodiversity component, the risk and the uncertainty were calculated for both the short and long term, as indicated in Appendix A. They are calculated for the individual ecosystem services (Table 5) and for the biodiversity components (Table 6).

Table 5 shows that the risk for genetic resources, climate regulation, pest and disease regulation and pollination is moderate in both the short and the long term. The risk for food is moderate in the short term and major in the long term. The risk for water regulation and erosion regulation is major in both the short and the long term. The risk for fresh water is massive in both the short and the long term. The risk for nutrient cycling and photosynthesis and primary production of macrophytes is massive in the short term and major in the long term.

The uncertainty is medium for all the ecosystem services in the short term, except for erosion regulation, for which uncertainty is high in the short term. Water regulation, erosion regulation and pest and disease regulation have high uncertainty in the long term, while all the other ecosystem services have medium uncertainty in the long term.

Table 5: Risk and uncertainty for ecosystem services

Ecosystem service	**Short term**		**Long term**	
	Risk	**Uncertainty**	**Risk**	**Uncertainty**
Food	0.19	0.66	0.21	0.59
Genetic resources	0.17	0.64	0.15	0.66
Fresh water	0.58	0.51	0.51	0.64
Climate regulation	0.11	0.59	0.10	0.59
Water regulation/cycling/purification	0.36	0.64	0.25	0.80
Erosion regulation	0.27	0.74	0.24	0.80
Nutrient cycling	0.51	0.42	0.43	0.64
Photosynthesis and primary production of macrophytes	0.63	0.38	0.43	0.64
Pest and disease regulation	0.12	0.85	0.09	0.82
Pollination	0.08	0.43	0.07	0.42

Table 6 presents the risk for the biodiversity components. For genetic diversity and native species diversity, the risk is major in both the short and the long term. For native habitat, the risk is massive in the short term and major in the long term. For threatened species and habitat of high conservation values, the risk is massive in both the short and the long term.

The uncertainty is low for habitat of high conservation values in the long term and medium in the short term. For all the others biodiversity components the uncertainty is medium for both the short and the long term.

Table 6: Risk and uncertainty for biodiversity components

Biodiversity	**Short term**		**Long term**	
	Risk	**Uncertainty**	**Risk**	**Uncertainty**
Genetic diversity	0.47	0.66	0.30	0.59
Native species diversity	0.47	0.66	0.36	0.64
Native habitat, community and/or ecosystem diversity	0.53	0.59	0.47	0.66
Threatened species	0.53	0.59	0.63	0.38
Habitat of high conservation values	0.63	0.38	0.67	0.31

These results are summarised by an index of risk, calculated as the mean percentage of reduction in all the ecosystem services (see PLH ERA guidance). The same calculation was performed for the risks of all the biodiversity components. Similarly, an index of uncertainty was calculated. These indexes, calculated for both short and long term, are presented in Table 7.

Table 7: Index of risk given by the mean percentage of reduction in ecosystem services and in biodiversity and mean uncertainty in ecosystem services and in biodiversity

	Short term		**Long term**	
	Risk	**Uncertainty**	**Risk**	**Uncertainty**
Ecosystem services	0.30	0.59	0.25	0.66
Biodiversity	0.52	0.57	0.49	0.52

In the worst case scenario, the overall effect of the snail invasion on the shallow freshwater wetlands of southern Europe is major on the ecosystem services both in the short and in the long term, and is massive on the biodiversity in the short term and major in the long term. The risk values for biodiversity are greater than for ecosystem services both in the short and in the long term. This can be explained by the fact that natural environments are considered and that the biodiversity components are more sensitive to perturbations. Moreover, the ecosystem services are based on functional components and are able to reduce the impact.

The uncertainty is medium both in the short term and in the long term, with comparable values for ecosystem services and biodiversity.

5. Evaluation of the *Pomacea* ERA procedure

The PLH ERA guidance includes a detailed procedure with different consecutive steps to assess the impacts of plant pests on biodiversity and ecosystem services. Gilioli et al. (2014) presented a summarised preliminary test of the ERA approach using the citrus longhorned beetle (*Anoplophora chinensis*) as an example. For the assessment presented in this scientific opinion, the complete approach was tested to evaluate the different steps of the ERA in detail; as a result, some aspects of the PLH ERA guidance were improved (see Section 2.1).

5.1. Scenarios

5.1.1. Population dynamics model

The ERA on *Pomacea* presented here includes different detailed steps, starting with a population dynamics model that was developed and presented in a previous scientific opinion (EFSA PLH Panel, 2013) to obtain information on the potential establishment and population density of the apple snail in Europe. The approach presented in this opinion, in which the probability of establishment is assessed by answering a set of questions, has not previously been generally applied in pest risk assessment (EFSA PLH Panel, 2013). An advantage of using a population dynamics model is that not only pest establishment, but that also variation in pest density, can be estimated. However, a disadvantage is that this approach requires many more resources. The resource requirement can be reduced in future pest risk assessments if generic modelling approaches are adopted and general modelling tools and platforms are used.

5.1.2. Definition of the service providing unit

In the *Pomacea* case study, only one service-providing unit (SPU) was identified, i.e. shallow, aquatic, fresh water areas containing aquatic macrophytes, such as wetlands, shallow lakes, river deltas and the littoral zone of deeper lakes and rivers, which simplified and shortened the assessment.

In this ERA, only one SPU was identified, which simplified and shortened the assessment. This might not be the case in other ERAs, in which two or more SPUs might be identified, consequently increasing the complexity of the assessment and the resources needed to perform it.

5.1.3. Definition of the temporal, spatial and biomass scales and the influence of resistance, resilience and management

Since the spread of *Pomacea* is very difficult to predict owing to the unknown specific importance of human-assisted spread as well as the importance of spread by birds, the Panel refers only to the area of potential establishment as predicted by the population dynamics model. The influence and the time variability of resistance, resilience and management lead to the consideration of different scenarios with respect to the temporal scale. Therefore, a short-term assessment 5 years after establishment (main influence: resistance of the ecosystem) and a long-term assessment 30 years after establishment (main influence: resilience) have been performed here. In other assessment more scenarios may need to be considered.

As described in Section 2.2, the driving force of the ecosystem change is the snail density. Knowledge of snail density (in terms of biomass per area or volume unit) allows prediction of the consequences of the pest on its host plants. This effect is the first to be considered when assessing the impacts of a plant pest on an ecosystem. In this study, the Panel performed the assessment in the worst-case scenario in terms of snail biomass. Moreover, the potential biomass of apple snails is decreased by considering the resistance and resilience of the ecosystem and the effect of control measures, rendering the assessment more realistic.

5.2. Rating system

The rating system described in the PLH ERA guidance is rather detailed. When applying it for the ERA of *Pomacea,* the method appeared to be easily applicable and transparent. Experts were asked to estimate the magnitude of an impact by assigning a percentage to the reduction in each ecosystem service or a biodiversity component. The uncertainty associated with these estimates was considered by distributing the expected impact over several categories between 1 and 5 (minimal to massive). In the approach used by the Panel, experts first individually provided their ratings, including their uncertainties for the different ratings, and then discussed their ratings in a meeting, which usually led to agreement on final ratings. This procedure improved the accuracy of the ratings and reduced the uncertainty in some cases.

5.3. New aspects for the environmental risk assessment

Since ecosystems have a systemic nature, the relationship between ecosystem services and traits is not expected to be linear. However, clusters that link traits and ecosystem services can be identified, and this approach was described in the ERA guidance. However, in this ERA, it appeared very complex to link the impact between ecosystem traits and biodiversity components and ecosystem services. Instead, a direct evaluation of the impact on ecosystem traits was shown to be highly informative, and can often be at least partly supported by scientific evidence. As a result, uncertainty of the assessment can be reduced. Therefore, the Panel assessed impacts of *Pomacea* on traits, ecosystem services and biodiversity separately instead of assessing them in clusters. Expert judgement was requested for all three aspects, taking into account the realised biomass of the snails (i.e. after reduction through resistance, resilience and management).

In contrast to the PLH ERA guidance, impacts on biodiversity and ecosystem services were then assessed in the same way, again with regard to the rating (the five different scales with the intervals applied to impacts on ecosystem services were also applied to impacts on biodiversity). This homogenises and simplifies the approach and is therefore also more user-friendly. The number of questions related to impacts on biodiversity in the PLH ERA guidance has been reduced and brought in line with the questions for impacts on ecosystem services.

An ERA for the area of origin of *Pomacea* was not performed, though this is proposed in the ERA guidance. The practical assessment of the PLH ERA guidance revealed that, since the ERA is based on a scenario analysis, an assessment of the area of origin is not logical, since the scenarios are developed for the area to be assessed and the assessment is based on the biomass that is predicted for the risk assessment area and on the impacts it has.

In addition, the *Pomacea* ERA focuses only on the risk assessment area and the results from the population dynamics model. As a result, the assessment is more straightforward and relates only to the situation in the invaded and potentially invaded area.

5.4. Simplification of ERA

In this case study of *Pomacea*, the Panel followed—with some modifications—the full approach presented in the PLH ERA guidance, to identify aspects that could be improved and/or simplified or made more flexible. It has already been indicated where simplification and improvement is possible. The Panel does not propose to perform a detailed ERA in all cases. Therefore, before starting an ERA, it is essential to define the level at which the assessment should or needs to be conducted. To simplify the ERA according to the needs and requirements, and to decide the level at which the ERA should be performed, it is necessary to consider the following three aspects and to develop the procedure in relation to these.

1. How much and which relevant knowledge is available?
2. What are the objectives of the risk assessor(s) for the ERA? On which level do they have to be addressed?
3. Which resources are available (finance, time, expertise)?

Ad 1) The ERA requires data on, for example, the traits of the species, the traits of the host plants, the composition of the ecosystem(s) that should be considered, the characteristics of the ecosystem services and the potential ecosystem services that could be affected. One of the advantages of the ERA approach is that it can be used even if not much information is available (EFSA PLH Panel, 2011; Gilioli et al., 2014). However, it needs to be clarified which information is absolutely essential to conduct the ERA—this should be evaluated by a step-by-step examination of data relevant for an ERA.

Ad 2) The objectives of the risk assessor(s) may be very simple—to quickly determine if the environment is likely to be affected by the pest via impacts on ecosystem services and biodiversity, but without going into too much detail. This might be a suitable approach when it is already clear, by assessing other impacts of the pest (e.g. on crop yield), that the requirements for the pest to be a quarantine pest are already fulfilled, even if the environmental impact is low. It could be the other way round, i.e. a very detailed ERA would be needed if the pest does not have significant impacts at the agricultural/horticultural or forestry level, but might have a serious impact on ecosystem services and biodiversity. In that case a detailed ERA could be useful to provide technical justification for classifying a pest as a quarantine pest.

Ad 3) The degree of complexity followed in an ERA could also depend on the resources that are available, e.g. how much money and time is available, who is available to do it, and which expertise is available. However, even if the outcomes of (1) and (2) indicate the need for a detailed approach, it might nevertheless be necessary to go for a simplified or shortened approach, if resources are limited. A ‘condensed version’ has the advantage that it allows at least a simple ERA to be carried out, if a full one is not possible. It is therefore important to develop a protocol for a simplified approach, in which relevant information is presented and all parts are assessed.

To decide in a systematic way which approach should be followed, it would be useful to have a scheme available that helps to decide which options for the ERA are adequate and which guides the assessor through the ERA. This scheme could have a standard part that should always be applied (the 'basics', i.e. basic assumptions, the scenario(s) and the general assessment) and a second part that helps to identify the level of detail based on the three aspects mentioned above.

5.5. Specific proposals for simplification

5.5.1. Assumptions

The text describing the assumptions needs to be as precise and detailed as possible to give the assessor a clear idea on how to do the ERA. To simplify this part, it is important to know which assumptions are most important and which ones might not be essential. By testing different combinations of assumptions, and ignoring some, the essential ones can be identified. Next, one should analyse what could be done to compensate for missing information, e.g. by simulation. For example, if it is not yet known whether a pest could be harmful to certain plants in the pest risk assessment area since only related species are present, the assumption could be simulated at different levels of impact (no impact, lower impact, same impact (as to related species), higher impact).

5.5.2. Traits

The available information on traits can be quite comprehensive but also very vague, depending on knowledge about the pest, the ecosystem and the ecosystem services affected, the current and potential host plants, and biotic and abiotic conditions in the risk assessment area. To select the most important traits, a decision tree could be developed, guiding the assessor to choose the traits in relation to the information available and the objectives of the assessment. In a simplified assessment, only the basic traits may be assessed. However, it is essential to know which traits should always be included ('basic traits') and which are less important or not essential.

5.5.3. Ecosystem services

A similar approach could be chosen to select the ecosystem services to be assessed. Depending on the pest and the pest risk assessment area, the list of ecosystem services could be quite different.

5.5.4. Assessment of the impacts on ecosystem services and biodiversity components

The rating system as used in this opinion does not need simplification, since it can be applied relatively easy. Similarly to logarithmic steps, the intervals chosen in the impact rating provide the range necessary to encompass a wide range of impact levels and also increase resolution at the lower end of the scale. This seems to be helpful in distinguishing between impacts, which is necessary for the rating of impacts on ecosystem services. This reasoning seems also to be true for the rating of the biodiversity components.

5.5.5. Flow charts

Revision of the entire ERA procedure and presenting it in the form of a flow chart would provide a clear overview of the ERA approach in terms of steps, different possibilities and a decision support scheme for the risk assessor.

The new approach could be discussed or presented to other European bodies dealing with ERA, with a view to complementing other risk assessments and harmonisation where possible and needed.

The Panel considers the procedure applied in the ERA to be an innovative method to approach the assessment of risk, which might influence other elements of a pest risk assessment.

In addition, current pest risk assessment approaches could be improved by using pest density to analyse the overall impact of the pest, as has been done in this assessment. And, similar to the scenario analysis followed in this opinion, the use of assumptions achieve in a well-defined analysis, or the use of a standardised scheme for performing the pest categorisation, could be useful improvements to the current pest risk assessment.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The European Food Safety Authority (EFSA) asked the Plant Health Panel (hereinafter referred to as the Panel) to deliver a scientific opinion on the risk the apple snail poses to the environment of the European Union (EU). The Panel was requested to review the current state of the art of the biology and ecology of apple snails of the genus *Pomacea*, and to perform an environmental risk assessment (ERA) using the invasive species of *Pomacea* as a case study for validating the Panel's guidance document on ERA (EFSA PLH Panel, 2011), hereinafter referred to as PLH ERA guidance. This was also deemed necessary since the Spanish pest risk analysis (Spanish Ministry of Environment and Rural and Marine Affairs, 2011) did not sufficiently address the environmental impacts of the apple snail (EFSA PLH Panel, 2012a).

In this scientific opinion, when the Panel refers to the apple snail, it refers specifically to *Pomacea maculata* and to *P. canaliculata.* As these species are closely related, their population dynamics pattern and potential impacts are assumed by the Panel to be similar.

In this document, the Panel presents the ERA of the apple snail for the EU territory, including an analysis and evaluation of the risk assessment methodology applied to the apple snail. In EFSA PLH Panel (2013), the Panel reviewed the current state of the art of the biology and ecology of the apple snail and used a population dynamics model to assess its establishment in terms of density distribution in Europe. The Panel used these results as a starting point for performing the ERA.

Conclusions concerning the methodological approach and its simplification

The PLH ERA guidance includes a detailed procedure with different consecutive steps to assess the impacts of plant pests on ecosystem traits, ecosystem services and biodiversity components. In the current opinion, when performing the assessment, the complete PLH ERA approach was tested to evaluate the different steps described in the ERA guidance. Some aspects of the guidance were modified to improve it, and suggestions were made to simplify the approach and to make it more flexible.

In this opinion, the results obtained by the population dynamics model developed for *P. canaliculata* (EFSA PLH Panel, 2013) are summarised to describe the potential establishment and population density of the apple snail in different areas of Europe. However, in the current opinion, the Panel assessed snail population densities not in terms of number of eggs, juveniles and adults, but instead using a snail biomass index to represent density, which combines the fresh weights of the snail stages and supports the evaluations of the impacts on ecosystem services and biodiversity.

Definition of the service-providing unit
In the *Pomacea* case study, only one service-providing unit (SPU) was identified, i.e. shallow fresh water areas containing macrophytes, such as wetlands, shallow lakes, river deltas and the littoral zone of deeper lakes and rivers, which simplified and shortened the assessment, consequently decreasing its complexity.

Temporal, spatial and biomass scales and the influence of resistance, resilience and management
In this assessment, only the area of potential establishment as predicted by the population dynamics model was taken into account. The influence and the time variability of resistance, resilience and management led to the consideration of two different scenarios for this case, a short-term assessment 5 years after establishment (main influence: resistance of the ecosystem) and a long-term assessment 30 years after establishment (main influence: resilience).

Rating system
The rating system described in the PLH ERA guidance document appeared easily applicable and transparent. Experts were asked to estimate the magnitude of impacts by assigning a percentage to the

expected reduction in each ecosystem service or a biodiversity component of between 0 and 100 %. Uncertainty was addressed by considering the distribution of the expected impact over the categories between 1 and 5 (minimal to massive). Experts first individually provided their ratings including the uncertainties, then discussed their ratings and agreed on final ratings. This procedure improved the accuracy of the ratings and reduced the uncertainty in some cases.

Changes made in the ERA approach applied for the Pomacea case
Creating traits–ecosystem services clusters as described in the PLH ERA guidance was found to be very complex. Therefore, the impacts on ecosystem traits, ecosystem services and biodiversity were assessed in a direct, separate evaluation using expert judgement. This procedure also reduced uncertainty, because at least some scientific evidence could be provided. To homogenise and simplify the approach, impacts on biodiversity and ecosystem services were assessed and rated in the same way. Since the ERA is based on a scenario analysis, an assessment of the area of origin is not considered logical, because scenarios are based on the biomass that is predicted for the risk assessment area by the population dynamics model and the impacts that are expected.

Simplification of ERA
The Panel does not propose to perform a detailed ERA in all cases. Therefore, before starting an ERA, it is essential to define the level at which the assessment should or needs to be conducted. Suggestions for different ways to implement the ERA are presented in the Section ‘Recommendations’.

Conclusions concerning environmental risks posed by *Pomacea*

According to the population dynamics model (EFSA PLH Panel, 2013) the area of potential establishment of *Pomacea* comprises wetlands of southern Europe (i.e. Spain, southern France, most of Italy and Greece) and the Balkans up to the latitude of the Danube River.

High potential biomass values (more than 20 g/m² in snail fresh weight) are predicted for a large number of coastal and inland Mediterranean locations, but realised biomass values were smaller (84 % of the potential biomass at the 5 years time horizon and 40 % of the potential biomass at the 30 years time horizon) after application of the scaling factors (resistance, resilience and management). The average realised snail biomass after 30 years is lower than after 5 years, because it is expected that (i) macrophytes that are non-palatable to *Pomacea* will replace palatable macrophytes, which will largely disappear, and (ii) natural enemies may reduce the apple snail density more efficiently at the longer time horizon.

The Panel assessed the effect of snail biomass on a number of ecosystem traits and assessed the impact of snail invasion on the ecosystem services in the worst-case scenario. In the context of the current ERA, considering that the driving force of the ecosystem change is apple snail biomass, some services are not expected to be modified, and only a selection of the provisioning services and regulating–supporting services have been retained for evaluation. The Panel also assessed the impact of snail invasion on biodiversity in the worst-case scenario, for both structural and conservation components. In order to systematically assess the impact of snail invasion on the ecosystem services and biodiversity components, a number of traits–services clusters and traits–biodiversity components clusters have been schematised by the Panel. For each ecosystem service and biodiversity component, the risk was calculated in both the short and the long term.

With regard to the ecosystem services, the Panel concludes that the presence of the apple snail results in a moderate risk for genetic resources, climate regulation, pest and disease regulation and pollination in both the short and the long term. The risk for food is moderate in the short term and major in the long term. The risk for water regulation and erosion regulation is major in both the short and the long term. The risk for fresh water is massive in both the short and the long term. The risk for nutrient cycling and photosynthesis and primary production of macrophytes is massive in the short term and major in the long term. In the worst case scenario, the overall effect of the snail invasion on the shallow freshwater wetlands of southern Europe is major on the ecosystem services both in the short and in the long term.

For the biodiversity component, the Panel concludes that the presence of the apple snail results in a major risk for genetic diversity and native species diversity in both the short and the long term. For native habitat, the risk is massive in the short term and major in the long term. For threatened species and habitat of high conservation value, the risk is massive in both the short and the long term. In the worst case scenario, the overall effect of the snail invasion on the shallow freshwater wetlands of southern Europe is massive on the biodiversity in the short term and major in the long term.

In future work, the methodology used in this opinion to produce the maps of the spatial distribution of impact on some ecosystem traits, ecosystem services and biodiversity components could also be compared with maps of special wetland areas under Natura 2000 (Council Directive 92/43 EEC). The objective of this comparison would be to visualise the relevant habitats present in the assessment area that are potentially affected by the presence of the apple snail. However, to do this in a scientifically sound way, it would be necessary to relate these maps more clearly to the quantitative analysis of the impacts on ecosystem traits, ecosystem services and the biodiversity components of those habitats considered in the ERA.

RECOMMENDATIONS

The Panel recommends the following:

1. Consider the use of a population dynamics model to estimate both establishment and population density of emerging pests in the risk assessment area.
2. Use the population density to assess the impact of pests on ecosystem services and biodiversity.
3. Do not consider the area of origin of the pest, but focus the assessment on the risk assessment area, in accordance with the scenario(s) being developed for the risk assessment area.
4. Evaluate ecosystem traits, biodiversity components and ecosystem services directly without quantifying the interactions represented in the traits–services and traits–biodiversity clusters.
5. Assess impacts on ecosystem services and biodiversity in the same way.
6. Define the level at which an ERA needs to be conducted before starting the assessment by considering the following questions:
    (a) How much and which relevant knowledge is available?
    (b) What are the objectives of the risk assessor(s) for the ERA and on which level do they have to be addressed?
    (c) Which resources are available to perform the ERA?
7. Consider a number of simplifications related to the description and selection of assumptions, the selection and the amount of detail to describe traits and ecosystem services, and the assessment of the impacts on ecosystem services and biodiversity.
8. Set out the whole revised ERA procedure in a flow chart to obtain a clear overview of the various steps and different possibilities, including a decision support scheme.
9. Discuss the new PLH ERA approach with other organisations involved in ERA, or present it to them, with the aim of complementing other risk assessments and harmonising where possible and needed.
10. Consider how the innovative method used to perform the ERA might influence other elements of a pest risk assessment.

REFERENCES

Aarts BG, Van Den Brink FW and Nienhuis PH, 2004. Habitat loss as the main cause of the slow recovery of fish faunas of regulated large rivers in Europe: the transversal floodplain gradient. River Research and Applications, 20, 3–23.

Aditya G and Raut S, 2002. Destruction of *Indoplanorbis exustus* (Planorbidae) eggs by *Pomacea bridgesi* (Ampullariidae). Molluscan Research, 22, 87–90.

Albrecht EA, Carreno NB and Castro-Vazquez A, 1999. A quantitative study of environmental factors influencing the seasonal onset of reproductive behaviour in the South American apple-snail *Pomacea canaliculata* (Gastropoda: Ampullariidae). Journal of Molluscan Studies, 65, 241–250.

Albrecht EA, Koch E, Carreno NB and Castro-Vazquez A, 2005. Control of the seasonal arrest of copulation and spawning in the apple snail *Pomacea canaliculata* (Prosobranchia: Ampullariidae): differential effects of food availability, water temperature, and day length. Veliger, 47, 169–174.

Anderson DM, 2009. Approaches to monitoring, control and management of harmful algal blooms (HABs). Ocean and Coastal Management, 52, 342–347.

Baker R, Benninga J, Bremmer J, Brunel S, Dupin M, Eyre D, Ilieva Z, Jarošík V, Kehlenbeck H and Kriticos D, 2012. A decision-support scheme for mapping endangered areas in pest risk analysis. EPPO Bulletin, 42, 65-73.

Bossard M, Feranec J and Otahel J, 2000. CORINE land cover technical guide: Addendum 2000. Technical Report No. 40. European Environment Agency Copenhagen, Denmark. 105 pp.

Brix H, 1994. Functions of macrophytes in constructed wetlands. Water Science and Technology, 29, 71–78.

Burela S and Martín PR, 2011. Evolutionary and functional significance of lengthy copulations in a promiscuous apple snail, *Pomacea canaliculata* (Caenogastropoda: Ampullariidae). Journal of Molluscan Studies, 77, 54–64.

Carlsson NOL, 2006. Invasive golden apple snails are threatening natural ecosystems in Southeast Asia. In: Global advances in ecology and management of golden apple snails. Eds Joshi RC and Sebastian LS. Nueva Ecija, Philippine Rice Research Institute, Muñoz, Philippines, 61–72.

Carlsson NOL, Brönmark C and Hansson LA, 2004. Invading herbivory: the golden apple snail alters ecosystem functioning in Asian wetlands. Ecology, 85, 1575–1580.

Carlsson NOL, Sarnelle O and Strayer DL, 2009. Native predators and exotic prey –an acquired taste? Frontiers in Ecology and the Environment, 7(10), 525–532, doi:10.1890/080093

Cazzaniga NJ, 1990. Predation of *Pomacea canaliculata* (Ampullariidae) on adult Biomphalariaperegrina (Planorbidae). Annals of Tropical Medicine and Parasitology, 48(1), 97–100.

Chorus I and Bartram J, 1999. Toxic cyanobacteria in water: a guide to their public health consequences, monitoring and management. E & FN Spon Press, WHO, 400 pp. Available online: www.who.int/water_sanitation_health/resourcesquality/toxicyanbact/en/

Curry GL and Feldman RM, 1987. Mathematical foundations of population dynamics. Published for the Texas Engineering Experiment Station, Texas A&M University System, by Texas A&M University Press (College Station),

de Nie HW, 1987. The decrease in aquatic vegetation in Europe and its consequences for fish populations. EIFAC/CECPI Occasional paper No 19, Rome, Italy, 52 pp.

Di Cola G, Gilioli G and Baumgartner, 1999. Mathematical models for age structured population dynamics. In: Ecological entomology. Eds Huffaker CB and Gutierrez AP. John Wiley & Sons, New York, USA, 503–534.

Diehl S, 1988. Foraging efficiency of three freshwater fish: effects of structural complexity and light. Oikos, 53, 203–214.

Diehl S, 1992. Fish predation and benthic community structure: the role of omnivory and habitat complexity. Ecology, 73, 1646–1661.

EFSA PLH Panel (EFSA Panel on Plant Health), 2011. Guidance on the environmental risk assessment of plant pests. EFSA Journal 2011;9(12):2460, 121 pp. doi:10.2903/j.efsa.2011.2460

EFSA PLH Panel (EFSA Panel on Plant Health), 2012a. Scientific Opinion on the evaluation of the pest risk analysis on *Pomacea insularum*, the island apple snail, prepared by the Spanish Ministry of Environment and Rural and Marine Affairs. EFSA Journal 2012;10(1):2552, 57 pp. doi:10.2903/j.efsa.2012.2552

EFSA PLH Panel (EFSA Panel on Plant Health), 2012b. Statement on the identity of apple snails. EFSA Journal 2012;10(4):2645, 11 pp. doi:10.2903/j.efsa.2012.2645

EFSA PLH Panel (EFSA Panel on Plant Health), 2013. Scientific Opinion on the assessment of the potential establishment of the apple snail in the EU. EFSA Journal 2013;11(12):3487, 49 pp. doi:10.2903/j.efsa.2013.3487

Engelhardt KA and Ritchie ME, 2001. Effects of macrophyte species richness on wetland ecosystem functioning and services. Nature, 411, 687–689.

Estebenet AL and Cazzaniga NJ, 1992. Growth and demography of *Pomacea canaliculata* (Gastropoda: Ampullariidae) under laboratory conditions. Malacological Review, 25, 1–12.

Estebenet AL and Martín PR, 2002. Workshop: “Biology of Ampullariidae”—Minireview—*Pomacea canaliculata* (Gastropoda: Ampullariidae): life-history traits and their plasticity. Biocell, 26, 83–89.

Estebenet AL and Martín PR, 2003. Shell interpopulation variation and its origin in *Pomacea canaliculata* (Gastropoda: Ampullariidae) from southern Pampas, Argentina. Journal of Molluscan Studies, 69, 301–310.

Gilioli G, Schrader G, Baker R, Ceglarska E, Kertész V, Lövei G, Navajas M, Rossi V, Tramontini S and van Lenteren J, 2014. Environmental risk assessment for plant pests: A procedure to evaluate their impacts on ecosystem services. Science of the Total Environment, 468, 475-486.

Guimarães CT, 1983. Biological control: *Pomacea haustrum* Reeve, 1856 (Mollusca pilidae) over planorbids under laboratory conditions. Revista de Saúde Pública, 17, 138–147.

Gutierrez AP, 1996. Applied population ecology: a supply–demand approach. John Wiley & Sons, New York, USA, 300 pp.

Haberl R, Perfler R and Mayer H, 1995. Constructed wetlands in Europe. Water Science and Technology, 32, 305–315.

Hansson LA, Brönmark C, Anders Nilsson P and Åbjörnsson K, 2005. Conflicting demands on wetland ecosystem services: nutrient retention, biodiversity or both? Freshwater Biology, 50, 705–714.

Hecnar SJ and M’Closkey RT, 1997. The effects of predatory fish on amphibian species richness and distribution. Biological Conservation, 79, 123–131.

Hofkin BV, Stryker GA, Koech DK and Loker ES, 1991. Consumption of *Biomphalaria glabrata* egg masses and juveniles by the ampullariid snails *Pila ovata*, *Lanistes carinatus* and *Marisa cornuarietis*. Acta Tropica, 49, 37–44.

Horgan FG, Stuart AM and Kudavidanageet EP, 2014. Impact of invasive apple snails on the functioning and services of natural and managed wetlands. Acta Oecologica, 54, 90–100.

Hostettmann K and Marston A, 1995. Saponins. Cambridge University Press, Cambridge, UK, 548 pp.

Istvánovics V, Osztoics A and Honti M, 2004. Dynamics and ecological significance of daily internal load of phosphorus in shallow Lake Balaton, Hungary. Freshwater Biology, 49, 232–252.

James MR, Hawes I and Weatherhead M, 2000. Removal of settled sediments and periphyton from macrophytes by grazing invertebrates in the littoral zone of a large oligotrophic lake. Freshwater Biology, 44, 311–326.

Joshi RC, San Martín R, Saez-Navarrete C, Alarcon J, Sainz J, Antonlin MM, Martin AR and Sebastian LS, 2008. Efficacy of quinoa (*Chenopodium quinoa*) saponins against golden apple snail (*Pomacea canaliculata*) in the Philippines under laboratory conditions. Crop Protection, 27, 553–557.

Koch EW, 2001. Beyond light: physical, geological, and geochemical parameters as possible submersed aquatic vegetation habitat requirements. Estuaries, 24, 1–17.

Kwong KL, Dudgeon D, Wong PK and Qiu JW, 2010. Secondary production and diet of an invasive snail in freshwater wetlands: implications for resource utilisation and competition. Biological Invasions, 12, 1153–1164.

Landsberg JH, 2002. The effects of harmful algal blooms on aquatic organisms. Reviews in Fisheries Science, 10, 113–390.

Liu J, He Y, Tan J, Xu C, Zhong L, Wang Z and Liao Q, 2012. Characteristics of *Pomacea canaliculata* reproduction under natural conditions. Chinese Journal of Applied Ecology, 23, 559–565.

Liu Y, Han W and Xian Z, 2011. Effect of different temperatures on growth, development and feeding of *Pomacea canaliculata*. Journal of Southern Agriculture, 42, 901–905.

Lodge DM, Cronin G, Van Donk E and Froelich AJ, 1998. Impact of herbivory on plant standing crop: comparisons among biomes, between vascular and nonvascular plants, and among freshwater herbivore taxa. In: The structuring role of submerged macrophytes in lakes. Eds Jeppesen E, Sondegaard Ma, Sondegaard Mo and Christoffersen K. Ecological Studies, 131, 149–171.

Maretić T, Perovic M, Vince A, Lukas D, Dekumyoy P and Begovac J, 2009. Meningitis and radiculomyelitis caused by *Angiostrongylus cantonensis*. Emerging Infectious Diseases. 15(6), 996–998.

Metz JA and Diekmann O, 1986. The dynamics of physiologically structured populations. Lecture notes in biomathematics. Springer-Verlag, Berlin, Germany, 511 pp.

Morrison WE and Hay ME, 2011. Feeding and growth of native, invasive and non-invasive alien apple snails (Ampullariidae) in the United States: invasive, eat more and grow more. Biological Invasions, 13, 945–955.

Nyström P, Hansson J, Månsson J, Sundstedt M, Reslow C and Broström A, 2007. A documented amphibian decline over 40 years: possible causes and implications for species recovery. Biological Conservation, 138, 399–411.

Perennou C, Beltrame C, Guelmami A, Vives PT and Caessteker P, 2012. Existing areas and past changes of wetland extent in the Mediterranean region: an overview. ecologia mediterranea, 38, 53-66.

Persson L and Crowder LB, 1998. Fish–habitat interactions mediated via ontogenetic niche shifts. In: The structuring role of submerged macrophytes in lakes. Eds Jeppesen E, Sondegaard Ma, Sondegaard Mo and Christoffersen K. Ecological Studies, 131, 3–23.

Petr T, 2000. Interactions between fish and aquatic macrophytes in inland waters: a review. Food and Agriculture Organisation (FAO). Technology and Engineering, 185 pp.

Pretty JN, Mason CF, Nedwell DB, Hine RE, Leaf S and Dils R, 2003. Environmental costs of freshwater eutrophication in England and Wales. Environmental Science and Technology, 37, 201–208.

Qiu J-W, Chan MT, Kwong KL and Sun J, 2011. Consumption, survival and growth in the invasive freshwater snail *Pomacea canaliculata*: does food freshness matter? Journal of Molluscan Studies, 77, 189–195.

Rai PK, 2009. Heavy metal phytoremediation from aquatic ecosystems with special reference to macrophytes. Critical Reviews in Environmental Science and Technology, 39, 697–753.

Rodríguez-Villafañe C, Bécares E and Fernández-Aláez M, 2007. Waterfowl grazing effects on submerged macrophytes in a shallow Mediterranean lake. Aquatic Botany, 86, 25–29.

Sand-Jensen K, Riis T, Vestergaard O and Larsen SE, 2000. Macrophyte decline in Danish lakes and streams over the past 100 years. Journal of Ecology, 88, 1030–1040.

San Martín R, Ndjoko K and Hostettmann K, 2008. Novel molluscicide against *Pomacea canaliculata* based on quinoa (*Chenopodium quinoa*) saponins. Crop Protection, 27, 310–319.

Scheffer M, 1998. Ecology of shallow lakes. Chapman & Hall, London, UK. 357 pp.

Scheffer M, Hosper SH, Meijer M-L, Moss B and Jeppesen E, 1993. Alternative equilibria in shallow lakes. Trends in Ecology and Evolution, 8, 275–279.

Seuffert ME and Martín PR, 2012. A lentic dweller in lotic habitats: the behaviour of the invasive South American apple snail *Pomacea canaliculata* in flowing water. Aquatic Ecology, 46, 129–142.

Seuffert ME and Martín PR, 2013. Juvenile growth and survival of the apple snail *Pomacea canaliculata* (Caenogastropoda: Ampullariidae) reared at different constant temperatures. SpringerPlus, 2, 312.

Shin-ichiro SM, Usio N, Takamura N and Washitani I, 2009. Contrasting impacts of invasive engineers on freshwater ecosystems: an experiment and meta-analysis. Oecologia, 158, 673–686.

Spanish Ministry of Environment and Rural and Marine Affairs, 2011. Pest risk analysis on the introduction of *Pomacea insularum* (d'Orbigny, 1835) into the EU. April 2011. Unpublished report, Spanish Ministry of Environment and Rural and Marine Affairs , Spain, 45 pp.

Stryker GA, Koech DK and Loker ES, 1991. Growth of *Biomphalaria glabrata* populations in the presence of the ampullariid snails *Pila ovata*, *Lanistes carinatus* and *Marisa cornuarietis*. Acta Tropica, 49, 137–147.

Vymazal J, 2007. Removal of nutrients in various types of constructed wetlands. Science of the Total Environment, 380, 48–65.

Wolter C, Minow J, Vilcinskas A and Grosch U, 2000. Long-term effects of human influence on fish community structure and fisheries in Berlin waters: an urban water system. Fisheries Management and Ecology, 7, 97–104.

Wood TS, Anurakpongsatorn P, Chaichana R, Mahujchariyawong J and Satapanajaru T, 2006. Heavy predation on freshwater bryozoans by the golden apple snail, *Pomacea canaliculata* Lamarck, 1822 (Ampullariidae). The Natural History Journal of Chulalongkorn University, 6, 31–36.

Yingying P, Shengzhang Y and Xiaoping D, 2008. Effects of temperature stress on development, feeding and survival of the apple snail, *Pomacea canaliculata* (Lamarck). Acta Phytophylacica Sinica, 35, 239–244.

APPENDICES

Appendix A. Ratings risk and confidence intervals

Experts must evaluate the reduction in ecosystem service provision and in structural biodiversity. The different expert evaluations result in means represented in the form of a discrete probability distribution for each variable, for both the short and the long term.

The expected reduction in ecosystem service provision (or in structural biodiversity) is assigned a percentage value ranging between 0 % and 100 %. These values are then allocated to one of five ratings (minimal, minor, moderate, major, massive). The range of percentage reduction in service associated with each rating (denoted by 'impact') is indicated in Table A1.

Table A1: Ratings of reduction in ecosystem services

	Rating				
	Minimal	**Minor**	**Moderate**	**Major**	**Massive**
Impact	Zero or negligible	] 0 %, 5 %]	] 5 %, 20 %]	] 20 %, 50 %]	] 50 %, 100 %]

The rating system here followed is similar to the suggested system in the PLH ERA guidance (EFSA PLH Panel, 2011).

For each ecosystem the expert has to provide the probability distribution of the reduction in ecosystem service provision by filling in Table A2, with $p_1, p_2, p_3, p_4, p_5 > 0$ and such that $p_1 + p_2 + p_3 + p_4 + p_5 = 1$.

Table A2: Scheme for the assignment of the probability to each of the five ratings

	Rating				
	Minimal	**Minor**	**Moderate**	**Major**	**Massive**
Impact	Zero or negligible	] 0 %, 5 %]	] 5 %, 20 %]	] 20 %, 50 %]	] 50 %, 100 %]
Probability	p_1	p_2	p_3	p_4	p_5

To calculate the risk of an ecosystem a representative point for each interval of percentage reduction must be chosen. The representative points are the mid points of the intervals and are reported in Table A3.

Table A3: Representative points for each interval of percentage reduction in an ecosystem

	Rating				
	Minimal	**Minor**	**Moderate**	**Major**	**Massive**
Impact	Zero or negligible	] 0 %, 5 %]	] 5 %, 20 %]	] 20 %, 50 %]	] 50 %, 100 %]
Midpoint	0	0.025	0.125	0.35	0.75

As indicated in step 3 of the PLH ERA guidance (EFSA PLH Panel, 2011), the risk associated with ecosystem i is calculated as follows:

$R_i = 0.025\,p_2 + 0.125\,p_3 + 0.35\,p_4 + 0.75\,p_5.$

In contrast to the PLH ERA guidance, here we do not scale the risk from 0 to 100 %, because this can cause unrealistic situations. For example, if an expert assigns all probability to the ‘massive’ class, scaling the risk between 0 % and 100 % will result in a risk of 1, which is not possible. Without scaling, the highest risk is 75 %, which is limiting but does not produce unrealistic cases.

Finally, the risk can be categorised, as in step 5 of the PLH ERA guidance (Table A4).

Table A4: Categories for the risk

	Rating				
	Minimal	**Minor**	**Moderate**	**Major**	**Massive**
Index of risk	Zero or negligible	] 0 %, 5 %]	] 5 %, 20 %]	] 20 %, 50 %]	] 50 %, 100 %]

Each reduction in ecosystem service provision and in structural biodiversity is evaluated by *K* experts. The probability distributions given by all the experts are combined using a mixture distribution (see Johnson et al., 1992). If the probability distribution of the *k*th expert is denoted by $\{p_1^k, p_2^k, p_3^k, p_4^k, p_5^k\}$, or, in table format:

	Rating				
	Minimal	**Minor**	**Moderate**	**Major**	**Massive**
Impact	Zero or negligible	] 0 %, 5 %]	] 5 %, 20 %]	] 20 %, 50 %]	] 50 %, 100 %]
Probability	p_1^k	p_2^k	p_3^k	p_4^k	p_5^k

then the mixture distribution is given by

	Rating				
	Minimal	**Minor**	**Moderate**	**Major**	**Massive**
Impact	Zero or negligible	] 0 %, 5 %]	] 5 %, 20 %]	] 20 %, 50 %]	] 50 %, 100 %]
Probability	$\sum_{k=1}^{K} w_k p_1^k$	$\sum_{k=1}^{K} w_k p_2^k$	$\sum_{k=1}^{K} w_k p_3^k$	$\sum_{k=1}^{K} w_k p_4^k$	$\sum_{k=1}^{K} w_k p_5^k$

where w_k are weights, satisfying

$$w_k > 0 \; and \; \sum_{k=1}^{K} w_k = 1.$$

If all the experts are at the same level, then $w_k = 1/K$.

The final risk is calculated on the mixture distribution that takes into account all the expert evaluations.

Finally, an uncertainty associated with the evaluation of an ecosystem service or a biodiversity component is calculated as the Shannon entropy (see the PLH ERA guidance):

$$U_i = -\sum_{j=1}^{K} p_j \log(p_j).$$

Variable U_i is normalised with respect to its maximum, that is log (K), and then multiplied by 100 to obtain a percentage (see the PLH ERA guidance):

$$U_i^* = 100\,\frac{U_i}{\log(K)}.$$

The uncertainty U_i^* will be classified according to a rating system based on three categories—low, medium and high—as indicated in Table A5.

Table A5: Categories for the uncertainty

	Rating		
	Low	**Medium**	**High**
Uncertainty	] 0 %, 33 %]	] 33 %, 67 %]	] 67 %, 100 %]

The expert is asked to provide a range of variability for resistance, resilience and management scaling factors, for both the short and the long term. For each one of these scaling factors, experts are requested to provide individually a mean value and a 95 % confidence interval of the estimated mean, that is an interval in which they think that the mean of the scaling factor will be with probability 0.95 (Table A6).

Table A6: Scheme for the assignment of 95 % confidence interval for scaling factor 1

Scaling factor	**Short term**		
	Mean value	M	
	95 % confidence interval	L	R

The value L is the lower bound of the interval, and the value R is the upper bound of the interval.

The interval may be, but is not necessarily, symmetrical with respect to the mean.

The expert evaluations are then combined to obtain a single 95 % confidence interval for the mean of each scaling factor. A scaling factor is a variable ranging between 0 and 1. A suitable distribution for such a variable is the beta distribution. Starting from the estimated mean and 95 % confidence interval for one expert it is possible to obtain the beta distribution of the mean of the scaling factor in the opinion of this expert. In total, we have K beta distributions for the scaling factor. These probability distributions are combined in a mixture distribution (see Johnson et al., 1992). From this final distribution it is possible to obtain a single 95 % confidence interval for the scaling factor that summarises all the expert evaluations.

REFERENCES

EFSA PLH Panel (EFSA Panel on Plant Health), 2011. Guidance on the environmental risk assessment of plant pests. EFSA Journal 2011;9(12):2460, 121 pp. doi:10.2903/j.efsa.2011.2460

Johnson NL, Kotz S and Balakrishnan N, 1992. Continuous univariate distributions, Vols. 1–2. John Wiley and Sons, New York, USA.

Appendix B. Questionnaire for expert consultation on environmental impact assessment

1. Guidelines for the assessment of the impact of snail invasion on ecosystem services and biodiversity

1.1. Introduction

The EFSA working group on *Pomacea* is performing an environmental risk assessment (ERA) of the apple snail in the EU following the methodology suggested in the PLH Guidance document on environmental risk assessment (EFSA PLH Panel, 2011).

We consider snail biomass to be the driver of the ecosystem change. The ERA of the apple snail in the EU is performed assuming the worst-case scenario, namely in the condition of maximum realised biomass.

The assessment procedure comprises four steps:

1. Evaluation of the potential biomass in the European wetlands. The spatial distribution of the potential biomass has been obtained by means of a population dynamics model and is reported in EFSA PLH Panel (2013). The realised biomass is obtained from the potential biomass using estimated scaling factors (ranging from 1 to 0) expressing the effect of ecosystem resistance, resilience and management in reducing the potential biomass. The mean values of the scaling factors were estimated during a first expert consultation meeting on 30 and 31 January 2014.
2. Establishing the relationships between the biomass and the ecosystems traits related to ecosystem service provision and biodiversity. The assessment was carried out during the meeting on 30 and 31 January 2014.
3. Definition of the traits–ecosystem services and traits–biodiversity clusters.
4. Provision of an estimate of the impact of the snail biomass on the ecosystem services and biodiversity of wetlands (no agricultural areas). The assessment is done under specific assumptions.

The objective of the attached questionnaire is to provide an estimate of the impact of the snail biomass on a selected group of ecosystem services and biodiversity components. The impact is expressed in terms of the percentage reduction in each service and biodiversity component. The rating system applied in this procedure allows the joint estimation of the impacts and the associated uncertainties for two time horizons (short term and long term).

This document presents guidance and information necessary to perform the assessment. The information provided is:

- the assumptions for the assessment;
- the list of ecosystem services and biodiversity components;
- the traits–services and traits–biodiversity clusters.

The guidance is provided for rating the impact using an Excel file (see Section 2 of this appendix).

Three groups of questions are presented:

- biomass scaling factors confidence intervals;
- biodiversity (structural biodiversity and conservation);
- ecosystems services (provisioning and supporting–regulating services).

After returning the information, the results will be merged to provide an average probability distribution for the effect on each ecosystem service and each category of biodiversity.

Subsequently, the outcome will be discussed with the experts involved.

1.2. General assumptions

The assessment is done considering these assumptions:

- The worst-case scenario is considered for the analysis. It corresponds to the maximum potential snail biomass of 31.5 g/m^2, as estimated by the population dynamics model. This value is scaled by the coefficients defined here as scaling factors. The scaling factors take into account the effects of resistance, resilience and management in reducing the maximum potential biomass to the maximum realised biomass.
- Two time horizons have been selected: short term (5 years) and long term (30 years). Five years after establishment is considered the period necessary to build up the maximum population biomass in the most favourable conditions in Europe. A period of 30 years is considered to account for the long-term effects due to ecosystem resilience and the possibility of implementing existing and possible new risk reduction options.
- The scaling factors have been estimated in the two time horizons. The product of the coefficients for resilience, resistance and management assumes values of 0.84 for the short term and 0.4 for the long term. This means that we expect a population abundance of 84 % of the maximum expected abundance after 5 years and of 40 % of the maximum abundance after 30 years.
- The assessment of the impacts on biodiversity and ecosystem services is performed at 84 % of the maximum biomass (26.5 g/m^2) for the short term, and at 40 % of the potential biomass (12.6 g/m^2) after 30 years.
- For the sake of simplicity the values of the coefficients reducing the potential biomass are the same for all the locations in the assessment area (EU). In addition, the traits–biomass relationships and the traits–biodiversity and the traits–service clusters are the same for all locations.

Experts applying their judgement to the specific questions in Sections 4 and 7 can assume that:

- The assessment is performed in an ideal service-providing unit (SPU) representing the ‘average condition’ of fresh water wetlands in the European locations that are most favourable for the apple snail (allowing the snail biomass to reach the maximum).
- The assessment is performed in this ideal SPU after 5 (short term) and 30 (long term) years during which time the snail biomass has reached 84 % and 40 %, respectively, of its potential biomass.
- The values assigned to the scaling factors indicate how resistance, resilience and management modify snail biomass and its impact. They also have implication in terms of representing the reaction of the ecosystem to the presence of the driving force (snail biomass and activity, including feeding).
- The snail biomass is stable and uniformly distributed.
- The change in the biomass component as well as in the ecosystem services provision levels is evaluated comparing the condition of this ideal SPU before and after the invasion at the two time horizons (after 5 years and 30 years from establishment).

- In the case of the ecosystem services, we are interested not in the contribution of this particular SPU to the general condition of the service at a higher spatial scale, but only in the change in the condition at the local level of this specific ideal SPU.

1.3. The probability distributions

For each category of biodiversity and each ecosystem service and both for the short and long term, each expert has to estimate the magnitude of the impact and the uncertainty associated to this estimation (how certain he/she feels about giving this estimation).

The impact is evaluated in terms of reduction in the provision level of an ecosystem service or in a biodiversity component, which is represented by a percentage ranging between 0 % (no reduction) and 100 % (max reduction).

To account for uncertainty the expected impact can be assigned to one or more of five different categories of impact represented in Table B1. These categories correspond to five classes of impact defined in qualitative terms as minimal, minor, moderate, major and massive. Each class is defined considering an interval of reduction in the ecosystem service provision level or in the biodiversity component (see Table B1).

A value between 0 and 1 has to be assigned to each class (probability of the corresponding impact). The sum of the single probabilities must be equal to 1, and the resulting probability distribution does not necessarily need to be symmetrical.

Table B1: Ratings of reduction in ecosystem services or biodiversity components

	Rating				
	Minimal	**Minor**	**Moderate**	**Major**	**Massive**
Impact	Zero or negligible	] 0 %, 5 %]	] 5 %, 20 %]	] 20 %, 50 %]	] 50 %, 100 %]

The expert needs to indicate the probability of these ratings based on how confident he/she feels about the prediction. This will provide the probability distribution of the reduction in this ecosystem service or biodiversity component.

<u>Example 1:</u> If the expert is totally confident that the percentage reduction can be assigned to the interval] 5 %, 20 %], he/she rates the impact in the single category ‘moderate’ (see yellow fill in example in Table B2) with a probability 1.

Table B2: Scheme for the assignment of the probability to each of the five ratings in example 1

	Rating					
	Minimal	**Minor**	**Moderate**	**Major**	**Massive**	**Total**
Impact	Zero or negligible	] 0 %, 5 %]	] 5 %, 20 %]	] 20 %, 50 %]	] 50 %, 100 %]	
Probability			1			**1**

<u>Example 2:</u> If the expert considers that there is more uncertainty about the estimation, he/she distributes the probability within more categories. For example, he/she could distribute the expected reduction in the ecosystem service or biodiversity component as illustrated in the yellow fills in Table B3.

Table B3: Scheme for the assignment of the probability to each of the five ratings in example 2

Rating

	Minimal	Minor	Moderate	Major	Massive	Total
Impact	Zero or negligible	] 0 %, 5 %]	] 5 %, 20 %]	] 20 %, 50 %]	] 50 %, 100 %]	
Probability		0.3	0.6	0.1		**1**

Example 3: The condition of maximum uncertainty is expressed by the expert assigning the same probability in all the intervals, as shown in the yellow fills in Table B4.

Table B4: Scheme for the assignment of the probability to each of the five ratings in example 3

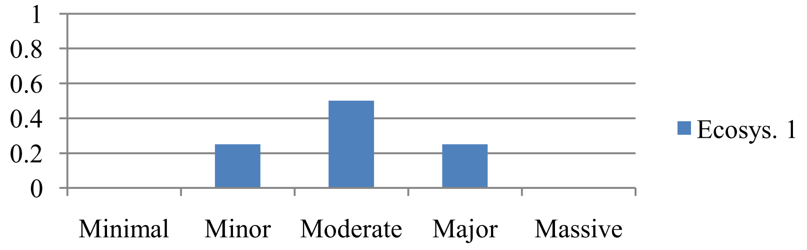
	Rating					
	Minimal	**Minor**	**Moderate**	**Major**	**Massive**	**Total**
Impact	Zero or negligible	] 0 %, 5 %]	] 5 %, 20 %]	] 20 %, 50 %]	] 50 %, 100 %]	
Probability	0.2	0.2	0.2	0.2	0.2	**1**

To help the expert in the evaluation, a histogram will appear as the expert fills in the Table B5. See Table B5 and subsequent histogram, which shows the ratings of an expert who estimates that the reduction is moderate at 50 %, major at 25 % and minor at 25 %.

Table B5: Scheme for the assignment of the probability to each of the five ratings

	Rating					
	Minimal	**Minor**	**Moderate**	**Major**	**Massive**	**Total**
Impact	Zero or negligible	] 0 %, 5 %]	] 5 %, 20 %]	] 20 %, 50 %]	] 50 %, 100 %]	
Probability	0	0.25	0.5	0.25	0	**1**

The corresponding histogram will be as follows:



1.4. Confidence intervals for resistance, resilience and management

The expert is asked to provide a range of variability for resistance, resilience and management scaling factors. For each of these scaling factors, a mean value was agreed on the basis of discussion between experts.

The experts are requested to provide their confidence in the agreed mean values.

In a separate sheet of the same Excel file the expert will find a table to be filled in with the 95 % confidence interval of the variables. The expert should indicate two values denoting the extremes of an interval in which he/she thinks that the variable will lie with probability 0.95.

Example 4**:** For the management you will find two tables, one for short-term management and the other for long-term management.

Management	SHORT TERM				LONG TERM		
	Mean value	0.99			Mean value	0.8	
	95% confidence interval				95% confidence interval		

The expert should fill in the yellow boxes with his/her estimates of 95 % confidence interval. The left value is the lower bound of the interval, and the right value is the upper bound of the interval. For example, if the expert thinks that management in the short term (that has mean 0.99) is between 0.985 and 0.995 with probability 0.95, the table will be filled in as follows

SHORT TERM		
Mean value	0.99	
95% confidence interval	0.985	0.995

Note that the interval may be symmetrical about the mean, but this is not necessarily the case. It is considered that, in the long term, the ecosystem is no longer resisting the invasion and the resistance value is therefore set to 1.

1.5. Trait and services

1.5.1. List of services

In the context of the current ERA, which considers the driving force for the change in ecosystem services to be apple snail biomass, some services are not expected to be modified and only the provisioning services and regulating–supporting services listed below have been retained for evaluation.

Provisioning services

Food

This category includes crops, livestock, capture fisheries, aquaculture, forage, as well as plant and animal products collected from the wild.

Genetic resources

Includes crop species and crop breeding, livestock species and breeds.

Fresh water

To consider in terms of both quantity (e.g. level of reservoir in inland water systems, rate of flow in rivers) and quality (e.g. turbidity or pollution).

Regulating and supporting services

Climate regulation

Regulation of source and sink of carbon dioxide, methane and sulphur dioxide and balanced heat transfer from solar radiation to the earth’s surface and from there to the troposphere. The carbon retention and methane release of the ecosystem contribute to climate regulation. Changes in land use and cover as a consequence of invasion influence the amount and local/regional impact on temperature and precipitation. These changes alter surface heat balance not only by changing surface albedo, but also by altering evaporative heat transfer caused by evapotranspiration from vegetation (highest in closed canopy forest) and by changes in surface roughness, which alter heat transfer between the relatively stagnant layer of air near the earth’s surface (the boundary layer) and the troposphere.

Regulating and supporting services

Water regulation/cycling/purification
Ecosystem changes produced by invasive pests affect the timing and magnitude of water runoff, flooding and aquifer recharge. The capacity of the ecosystems to filter and purify chemical waste as well as pathogen and organic pollution can also be modified.

Erosion regulation
Change in land use and cover due to the action of invasive pests can exacerbate soil degradation and erosion. Vegetation removal leaves soils vulnerable to massive increases in soil erosion by wind and water, especially on steep terrain, and when accompanied by other stressors (e.g. fire).

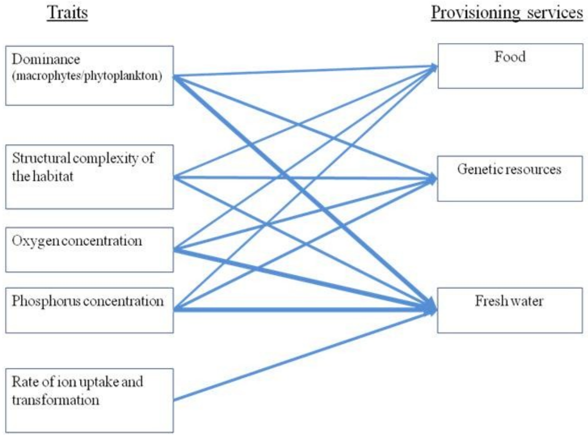
Nutrient cycling
These services may be affected by changes in decomposition rates, soil carbon mineralisation, geomorphological disturbance, as well as succession. Changes in ecosystems (e.g. modifications in land cover due to the introduction of invasive pests and the consequent change in net flux of biomass into the soil) may slow the rate of soil formation and degrade soil fertility over time, reducing the suitability of land for future agricultural use. Modification in the biological buffer limiting the transfer of nutrients from terrestrial to aquatic systems causes the release of huge quantities of phosphorus, nitrogen and sediments to streams and other aquatic ecosystems, causing a variety of negative impacts (increased sedimentation, turbidity, eutrophication and coastal hypoxia). Changes in decomposition rate, such as might occur if an invasive pest altered the litter chemistry, can affect nutrient cycling. Nutrient cycling can also be altered by invasive plants that fix nitrogen, leach chemicals and inhibit nitrogen fixation by other species and release compounds that alter nutrient availability or retention, including nitrogen and phosphorus.

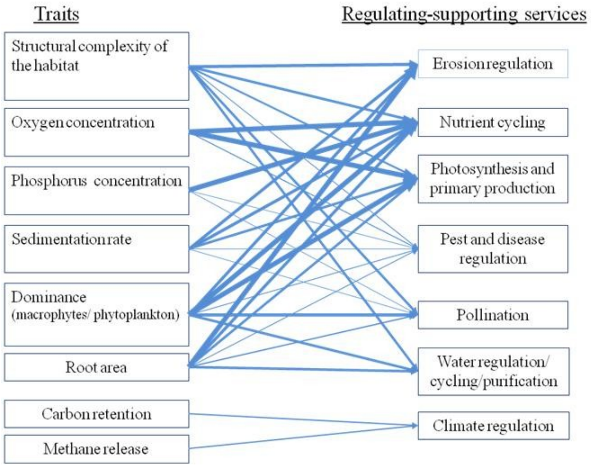
Photosynthesis and primary production
Primary production increases or decreases if an invasion leads to a shift in the major vegetation type of an area. Modifications in the plant community may affect the assimilation or accumulation rate of energy and nutrients. Changes in the net primary production can result in modification of terrestrial and aquatic food webs.

Pest and disease regulation
Ecosystem modifications due to the introduction of invasive pests can reduce the pest control services provided by natural enemies. This is due normally to direct competitive or predatory (intra-guild) interactions between the invaders and the natural pool of pest regulators. Invasive pests can also introduce new pathogens or create more suitable habitats for the establishment of new vectors and pathogens in the new environments.

Pollination
The introduction of invasive pests in new environments can modify the distribution, abundance and host range of native pollinators. The modification of the native vegetation due to an invasive plant can affect the native community of pollinators.

1.5.2. Traits–services clusters





1.6. Traits–biodiversity clusters

1.6.1. List of the biodiversity components

In order to assess the consequences for biodiversity caused by pest invasion, both structural and conservation components are considered as follows:

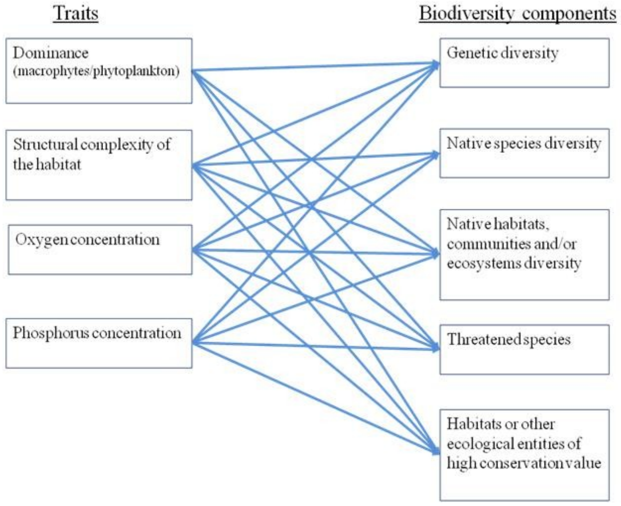
Structural component of biodiversity

- Genetic diversity
- Native species diversity
- Native habitats, communities and/or ecosystems diversity

Conservation component of biodiversity

- Threatened species
- Habitats or other ecological entities of high conservation value

1.6.2. Traits–biodiversity clusters



1.7. List of questions

Considering the assumptions given in Section 1.2 of this appendix, the traits–biomass relationships (see histograms in Section 4.2 of the scientific opinion) and the clusters in Section 1.6 of this appendix, use your best judgement to estimate the following values.

1.7.1. Scaling factors (coefficients) for calculation of realised biomass

1.7.1.1. Resistance

i. Provide a mean value of the expected effect of resistance of the ecosystem in reducing the potential biomass of the snail in the short term (5 years) (0 = max resistance; 1 = no resistance).

ii. Provide an estimate of the 95 % confidence interval on the mean value of the expected resistance of the ecosystem to the snail invasion in the short term.

iii. Provide a mean value of the expected effect of resistance of the ecosystem in reducing the potential biomass of the snail in the long term (30 years) (0 = max resistance; 1 = no resistance).

iv. Provide an estimate of the 95 % confidence interval on the mean value of the expected resistance of the ecosystem to the snail invasion in the long term.

1.7.1.2. Resilience

i. Provide a mean value of the expected effect of resilience of the ecosystem in reducing the potential biomass of the snail for the short term (5 years) (0 = max resilience; 1 = no resilience).

ii. Provide an estimate of the 95 % confidence interval on the mean value of the expected resilience of the ecosystem to the snail invasion in the short term.

iii. Provide a mean value of the expected effect of resilience of the ecosystem in reducing the potential biomass of the snail in the long term (30 years) (0 = max resilience; 1 = no resilience).

iv. Provide an estimate of the 95 % confidence interval on the mean value of the expected resilience of the ecosystem to the snail invasion in the long term.

1.7.1.3. Management

i. Provide a mean value of the expected effect of management measures in reducing the potential biomass of the snail in the short term (5 years) (0 = max effect of management; 1 = no effect of management).

ii. Provide an estimate of the 95 % confidence interval on the mean value of the effect of the expected management measures in reducing the potential snail biomass in the short term.

iii. Provide a mean value of the expected effect of management measures in reducing the potential biomass of the snail for the long term (30 years) (0 = max effect of management; 1 = no effect of management).

iv. Provide an estimate of the 95 % confidence interval on the mean value of the effect of the expected management measures in reducing the potential snail biomass in the long term.

1.7.2. Biodiversity

1.7.2.1. Structural biodiversity

i. To what extent is genetic diversity likely to decrease in the short term as a result of invasion?

ii. To what extent is genetic diversity likely to decrease in the long term as a result of invasion?

iii. To what extent is there a possible decline in native species diversity in the short term as a result of invasion?

iv. To what extent is there a possible decline in native species diversity in the long term as a result of invasion?

v. To what extent are changes likely in the native habitats, communities and/or ecosystems diversity in the short term as a result of invasion?

vi. To what extent are changes likely in the native habitats, communities and/or ecosystems diversity in the short term as a result of invasion?

1.7.2.2. Biodiversity–conservation

i. To what extent are there any threatened species expected to be affected in the short term as a result of invasion?

ii. To what extent are there any threatened species expected to be affected in the long term as a result of invasion?

iii. To what extent is there an expected impact on habitats or other ecological entities of high conservation value in the short term as a result of invasion?

iv. To what extent is there an expected impact on habitats or other ecological entities of high conservation value in the long term as a result of invasion?

1.7.3. Ecosystem services

i. How great is the magnitude of reduction in the provisioning services affected in the area of assessment in the short term? Provide an estimate for each ecosystem service.

ii. How great is the magnitude of reduction in the provisioning services affected in the area of assessment in the long term? Provide an estimate for each ecosystem service.

iii. How great is the magnitude of the reduction in the regulating and supporting services affected in the area of assessment in the short term? Provide an estimate for each ecosystem service.

iv. How great is the magnitude of the reduction in the regulating and supporting services affected in the area of assessment in the long term? Provide an estimate for each ecosystem service.

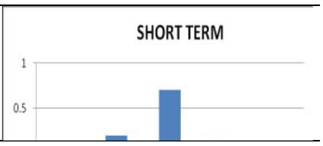
2. The questionnaire

The questionnaire is presented in an Excel file composed of four sheets:

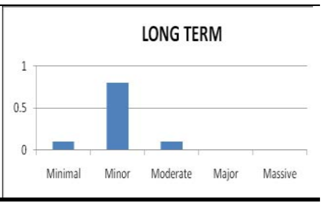
- Ecosystem services provisioning
- Ecosystem services regulating and supporting
- Biodiversity
- Scaling factors

For each provisioning, regulating and supporting service and each biodiversity component retained for evaluation, experts should provide a rating for the short term and the long term. Estimates and their corresponding uncertainty will then be presented in the form of a probability distribution as shown in the example in the tables and corresponding graphs below.

e.g. Ecosystem service 1	Rating, short term					
	Minimal	Minor	Moderate	Major	Massive	
Impact	Zero or negligible	] 0 %, 5 %]	] 5 %, 20 %]	] 20 %, 50 %]	] 50 %, 100 %]	
Probability		0.2	0.7	0.1		1



Comments						
	Rating, long term					
	Minimal	**Minor**	**Moderate**	**Major**	**Massive**	
Impact	Zero or negligible	] 0 %, 5 %]	] 5 %, 20 %]	] 20 %, 50 %]	] 50 %, 100 %]	
Probability	0.1	0.8	0.1			**1**
Comments						



Regarding the scaling factors, resistance, resilience and management, experts are requested to estimate, for both the short term and long term, the upper and lower bounds of the confidence intervals, as shown in the following tables.

Resistance	**Short term**		**Long term**	
	Mean value	0.9	Mean value	1
	95 % confidence interval			

Resilience	**Short term**		**Long term**	
	Mean value	0.95	Mean value	0.5
	95 % confidence interval		95 % confidence interval	

Management	**Short term**		**Long term**	
	Mean value	0.99	Mean value	0.8
	95 % confidence interval		95 % confidence interval	

REFERENCES

EFSA PLH Panel (EFSA Panel on Plant Health), 2011. Guidance on the environmental risk assessment of plant pests. EFSA Journal 2011;9(12):2460, 121 pp. doi:10.2903/j.efsa.2011.2460

EFSA PLH Panel (EFSA Panel on Plant Health), 2013. Scientific Opinion on the assessment of the potential establishment of the apple snail in the EU. EFSA Journal 2013;11(12):3487, 49 pp. doi:10.2903/j.efsa.2013.3487

GLOSSARY AND ABBREVIATIONS

Biodiversity: the variety of living organisms and the ecological complexes of which they are part (Harrington et al., 2010). It covers genetic, structural and functional components, which are represented at different organisational levels, from within-organism to individual organism, species, population, community and ecosystem levels (adapted from Secretariat of the CBD (2002), MEA (2003a) and extended according to Noss (1990)).

Community or biocenosis: an association of interacting populations, usually defined by the nature of their interactions or by the place in which they live (Ricklefs and Miller, 1999).

Disturbance: an event or change in the environment that alters the composition and successional status of a biological community and may deflect succession onto a new trajectory, such as a forest fire or hurricane, glaciation, agriculture and urbanisation (Art, 1993).

Driving factor (also called a driving force or simply driver): a factor directly or indirectly causing ecosystem change. A direct driver unequivocally influences ecosystem processes by itself, while an indirect driver operates by altering one or more direct drivers. The indirect drivers are underlying (root) causes that are formed by a complex of social, political, economic, demographic, technological, and cultural variables. Collectively, these factors influence the level of production and consumption of ecosystem services. The causal linkage is almost always mediated by other factors (Tomich et al., 2010).

Ecological disturbance: see Disturbance.

Ecological niche: the ecological role of a species in the community; the many ranges of conditions and resource qualities within the organism or species persists, often conceptualised as an abstract multidimensional space (Ricklefs, 1990).

Ecological habitat of a species: the place where an organism normally lives, often characterised by a dominant plant form (e.g. forest habitat) or physical characteristic (stream habitat) (Ricklefs, 1990).

Ecosystem: a dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit (MEA, 2005).

Ecosystem processes: actions or events that result in the flow of energy and the cycling of matter (Ellis and Duffy, 2008). Examples of ecosystem processes include decomposition, production, water and nutrient cycling (MEA, 2003b).

Ecosystem services: benefits that humans recognise as obtained from ecosystems that support, directly or indirectly, their survival and quality of life; ecosystem services include provisioning, regulating and cultural services that directly benefit people, and the supporting services needed to maintain the direct services (MEA, 2005; Harrington et al., 2010).

- **Provisioning services:** products obtained from ecosystems (Harrington et al., 2010).
  - **Food:** this category includes crops, livestock, capture fisheries, aquaculture, forage, as well as plant and animal products collected from the wild.
  - **Genetic resources:** includes crop species and crop breeding, livestock species and breeds.
  - **Fresh water:** to consider both in term of quantity (e.g. level of reservoir in inland water systems, rate of flow in rivers) and quality (e.g. turbidity or pollution).
- **Regulating and supporting services**

  Regulating services: benefits obtained from regulation of ecosystem processes (Harrington et al., 2010).

Supporting services: services necessary for the production of all other ecosystem services (Harrington et al., 2010).

- **Climate regulation:** regulation of source and sink of carbon dioxide, methane and sulphur dioxide and balanced heat transfer from solar radiation to the earth's surface and from there to the troposphere. The carbon retention and methane release of the ecosystem contribute to the climate regulation. Changes in land use and cover as a consequence of invasion influence the amount and local/regional impact on temperature and precipitation. These changes alter surface heat balance not only by changing surface albedo, but also by altering evaporative heat transfer caused by evapotranspiration from vegetation (highest in closed canopy forest), and by changes in surface roughness, which alter heat transfer between the relatively stagnant layer of air near the earth's surface (the boundary layer) and the troposphere.

- **Water regulation/cycling/purification:** ecosystem changes produced by invasive pests affect the timing and magnitude of water runoff, flooding and aquifer recharge. The capacity of the ecosystems to filter and purify chemical waste as well as pathogen and organic pollution can also be modified.

- **Erosion regulation:** change in land use and cover due to the action of invasive pests can exacerbate soil degradation and erosion. Vegetation removal leaves soils vulnerable to massive increases in soil erosion by wind and water, especially on steep terrain, and when accompanied by other stressors (e.g. fire).

- **Nutrient cycling:** these services may be affected by changes in decomposition rates, soil carbon mineralisation, geomorphological disturbance, as well as succession. Changes in ecosystems (e.g. modifications in land cover due to the introduction of invasive pests and the consequences change in net flux of biomass into the soil) may slow the rate of soil formation and degrade soil fertility over time, reducing the suitability of land for future agricultural use. Modification in the biological buffer limiting the transfer of nutrients from terrestrial to aquatic systems causes the release of huge quantities of phosphorus, nitrogen and sediments to streams and other aquatic ecosystems, causing a variety of negative impacts (increased sedimentation, turbidity, eutrophication and coastal hypoxia). Changes in decomposition rate, such as might occur if an invasive pest altered the litter chemistry, can affect nutrient cycling. Nutrient cycling can also be altered by invasive plants that fix nitrogen, leach chemicals and inhibit nitrogen fixation by other species and release compounds that alter availability or retention of nutrients, including nitrogen and phosphorus.

- **Photosynthesis and primary production:** primary production increases or decreases if an invasion leads to a shift in the major vegetation type of an area. Modifications in the plant community may affect the assimilation or accumulation rate of energy and nutrients. Changes in the net primary production can result in modification of terrestrial and aquatic food webs.

- **Pest and disease regulation:** ecosystem modifications due to the introduction of invasive pests can reduce the pest control services provided by natural enemies. This is normally due to direct competitive or predatory (intra-guild) interactions between the invaders and the natural pool of pest regulators. Invasive pests can also introduce new pathogens or create more suitable habitats for the establishment of new vectors and pathogens in the new environments.

- **Pollination:** the introduction of invasive pests in new environments can modify the distribution, abundance and host range of native pollinators. The modification of the native vegetation due to an invasive plant can affect the native community of pollinators.

Ecosystem structure: attributes related to the instantaneous physical state of an ecosystem. Several characteristics can be used to describe ecosystem structure, for example species population density, species richness or evenness, and standing crop biomass (US EPA, 2009).

EFSA: European Food Safety Authority.

Environmental risk assessment: a process of predicting whether the presence of a pest gives rise to a risk of adverse effects on the environment (EFSA PLH Panel, 2010, 2011).

Environment: natural environment, encompassing all living and non-living entities occurring naturally on earth or some region thereof (Johnson et al., 1997).

ERA: environmental risk assessment.

PLH ERA guidance: PLH EFSA guidance on environmental risk assessment (EFSA PLH Panel, 2011).

Functional group: a collection of organisms with similar functional trait attributes (Gitay and Noble, 1997; Harrington et al., 2010).

Functional trait: a feature of an organism which has demonstrable links to the organism's function (Lavorel et al., 1997; Harrington et al., 2010). Thus, a functional trait determines the organism's response to pressures (response trait) and/or its effects on ecosystem processes or services (effect trait). Functional traits are considered to reflect adaptations to variation in the physical and biotic environment and trade-offs (ecophysiological and/or evolutionary) among different functions within an organism. In plants, functional traits include morphological, ecophysiological, biochemical and regeneration traits, including demographic traits (at population level). In animals, these traits are combined with life history and behavioural traits (e.g. guilds: organisms that use similar resources/habitats). The traits addressed in this scientific opinion are the following:

- **Traits related to the macrophytes**
  - Edible macrophyte biomass
  - Biomass of non-edible macrophytes
  - Dominance (macrophytes/phytoplankton)
  - Macrophyte species diversity
  - Structural complexity of the habitat
- **Traits related to water quality**
  - Oxygen concentration
  - Phosphorus concentration
  - Sedimentation rate
  - pH (percentage of variation)
  - Denitrification
- **Traits related to biodiversity**
  - Aquatic invertebrates biodiversity
  - Amphibian biodiversity
  - Fish biodiversity
  - Bird biodiversity
  - Zooplankton biodiversity
  - Zooplankton biomass
  - Periphyton biomass

Genetic diversity: a measure of the amount of genetic variation in a group of individuals (e.g. population, species). It is commonly quantified using heterozygosity (the probability that two randomly chosen alleles are different) (Hartl and Clark, 2007).

Herbivore: an organism that consumes living plants or their parts (Ricklefs, 1990).

Impact/consequence: a measure of whether changes in state variables have a negative or positive effect on individuals, society and/or environmental resources. There is an impact if the state no longer equates to service provision (Harrington et al., 2010).

Invasibility/invasiveness: the ease with which a habitat is invaded (Booth et al., 2003).

Invasive alien species: an alien species whose introduction and/or spread threatens biological diversity (CBD, 2002).

Pathogen: a micro-organism causing disease (FAO, 2013).

Pest: any species, strain or biotype of plant, animal or pathogenic agent injurious to plants or plant products (FAO, 2013).

Phytophage: see Herbivore.

PLH: Plant Health.

Predator: a natural enemy that preys and feeds on other animal organisms, more than one of which are killed during its lifetime (FAO, 2013).

Resilience: an ecosystem's ability to recover and retain its structure and function following a transient and exogenous shock event (Harrington et al., 2010).

Resistance: the ability of the ecosystem to continue to function without change when stressed by a disturbance that is internal to the system (Harrington et al., 2010).

Scale (extent and grain): the spatial or temporal dimension of an object or process characterised by both grain and extent (Turner and Gardner, 1991). Grain is the spatial and temporal resolution chosen to analyse a given data set, whereas extent is the size of the study and the total duration over which measurements are made (Schneider, 1994).

Scaling factors: resilience, resistance and management.

Service-providing unit: a functional unit whose components (individuals, species or communities) are characterised by functional traits defining their ecological role (Vanderwalle et al., 2008).

Scenario analysis: attempts to explore what future developments may be triggered by a driving force, in this case an exogenous driving force, i.e. a driving force that cannot or can only partly be influenced by decision makers (Henrichs et al., 2010). Scenario analysis includes explicitly combination of qualitative and quantitative information and estimates (EEA, 2001). Most of the work is based on qualitative evaluation that can be translated into quantitative assumptions on the final state of the system (Henrichs et al., 2010).

Traits–services clusters: multiple associations between traits and services (De Bello et al., 2010).

Trophic links/interactions/relations: any reported feeding or trophic relation between two species in a web (Cohen and Briand, 1984). This association means that one species consumes any part or product of another species, for example an insect feeding on any part of a plant or ants feedings on honeydew excreted by aphids.

Uncertainty: the inability to determine the true state of affairs of a system (Haimes, 2009). It may arise at different stages of risk assessment owing to lack of knowledge or to natural variability (EFSA PLH Panel, 2010).

Vector: any living or non-living carrier that transports living organisms intentionally or unintentionally (ICES, 2004).

Wetlands: the most widely accepted definition is the one set out in the text of the Convention on Wetlands, signed in Ramsar, Iran, in 1971 (IUCN, 1971), the first international effort to protect these important habitats. According to Article 1.1 of the Convention, wetlands are:

> *areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres*.

In addition, for the purpose of protecting coherent sites, Article 2.1 provides that wetlands be included in the Ramsar List of internationally important wetlands:

> *may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands*.

REFERENCES

Art HW, 1993. The dictionary of ecology and environmental science. Henry Holt and Company, New York, NY, USA, 642 pp.

Booth BD, Murphy SD and Swanton CJ, 2003. Weed ecology in natural and agricultural systems. CABI Publishing, Cambridge, MA, USA, 288 pp.

CBD (Convention on Biological Diversity), 2002. Glossary of Terms. Available online: www.cbd.int/invasive/terms.shtml

Cohen JE and Briand F, 1984. Trophic links of community food web. Proceedings of the National Academy of Sciences of the United States of America, 81, 4105–4109.

De Bello F, Lavorel S, Diaz S, Harrington R, Cornelissen JHC, Bardgett RD, Berg MP, Cipriotti P, Feld CK, Hering D, da Silva PM, Potts SG, Sandin L, Sousa JP, Storkey J, Wardle DA and Harrison PA, 2010. Towards an assessment of multiple ecosystem processes and services via functional traits. Biodiversity and Conservation, 19, 2873–2893.

EEA (European Environment Agency), 2001. Scenarios as tools for international environmental assessments. Environmental Issue Report 24. EEA, Copenhagen, Denmark, 1–31.

EFSA PLH Panel (EFSA Panel on Plant Health), 2010. Guidance on a harmonised framework for pest risk assessment and the identification and evaluation of pest risk management options by EFSA. EFSA Journal 2010;8(2):1495, 68 pp. doi:10.2903/j.efsa.2010.1495

EFSA PLH Panel (EFSA Panel on Plant Health), 2011. Guidance on the environmental risk assessment of plant pests. EFSA Journal 2011;9(12):2460, 121 pp. doi:10.2903/j.efsa.2011.2460

Ellis E and Duffy JE, 2008. Ecosystem. In: Encyclopedia of Earth. Ed. Cleveland CJ. Environmental Information Coalition, National Council for Science and the Environment, Washington DC, USA. Available online: www.eoearth.org/article/Ecosystem?topic=58074

FAO (Food and Agriculture Organization of the United Nations), 2013. International standards for phytosanitary measures. ISPM No. 5—Glossary of phytosanitary terms. Secretariat of the International Plant Protection Convention. Rome, Italy, 35 pp.

Frankham R, Ballou JD and Briscoe DA, 2002. Introduction to conservation genetics. Cambridge University Press, Cambridge, UK, 617 pp.

Gitay H and Noble IR, 1997. What are functional types and how should we seek them? In: Plant functional types: their relevance to ecosystem properties and global change. Eds Smith TM, Shugart HH and Woodward FI. Cambridge University Press, New York, NY, USA, 388 pp.

Haimes YY, 2009. Risk modeling, assessment, and management. 3rd edn. John Wiley and Sons, 1010 pp.

Harrington R, Anton C, Dawson TP, de Bello F, Feld CK, Haslett JR, Kluvánkova-Oravská T, Kontogianni A, Lavorel S, Luck GW, Rounsevell MDA, Samways MJ, Settele J, Skourtos M, Spangenberg JH, Vandewalle M, Zobel M and Harrison PA, 2010. Ecosystem services and biodiversity conservation: concepts and a glossary. Biodiversity and Conservation, 19, 2773–2790.

Hartl DL and Clark AG, 2007. Principles of population genetics, 4th ed. Sinauer Associates Publishers, Sunderland, MA, USA, 565 pp.

Henrichs T, Zurek M, Eickhout B, Kok K, Raudsepp-Hearne C, Ribeiro T, Van Vuuren D and Volkery A, 2010. Scenario development and analysis for forward-looking ecosystem assessments. In: Ecosystems and human well-being: a manual for assessment practitioners. Eds Ash N, Blanco H, Brown C, Garcia K, Henrichs T, Lucas N, Raudsepp-Hearne C, David Simpson R, Scholes R, Tomich T, Vira B and Zurek M. Island Press, London, UK.

IUCN (International Union for Conservation of Nature), 1971. Convention on wetlands: what are wetlands? Ramsar Information Paper No 1. The Ramsar Convention Secretariat, Switzerland. Available online: www.ramsar.org

ICES (International Council for the Exploration of the Sea), 2004. Code of Practice on the Introductions and Transfers of Marine Organisms. 30 pp.

Johnson DL, Ambrose SH, Bassett TJ, Bowen ML, Crummey DE, Isaacson JS, Johnson DN, Lamb P, Saul M and Winter-Nelson AE, 1997. Meanings of environmental terms. Journal of Environmental Quality, 26, 581–589.

Lavorel S, McIntyre S, Landsberg J and Forbes TDA, 1997. Plant functional classification: from general groups to specific groups based on response to disturbance. Trends in Ecology and Evolution, 12, 474–478.

MEA (Millennium Ecosystem Assessment), 2005. Ecosystems and human well-being: synthesis, Island Press, Washington, DC, USA, .

MEA (Millennium Ecosystem Assessment), 2003a. Appendix 4—Glossary. Ecosystems and human well-being – a framework for assessment. Island Press, Washington DC, USA, 208–216.

MEA (Millennium Ecosystem Assessment), 2003b. Appendix D—Glossary. Ecosystems and human well-being – policy responses. Island Press, Washington DC, USA.

Noss RF, 1990. Indicators for monitoring biodiversity: a hierarchical approach. Conservation Biology, 4, 355–364.

Ricklefs RE and Miller GL, 1999. Ecology, 4th ed. W. H. Freeman and Co. Ltd, New York, NY, USA.

Ricklefs RE, 1990. Ecology, 3rd ed. W. H. Freeman and Co. Ltd, New York, NY, USA.

Schneider DC, 1994. Quantitative ecology, spatial and temporal scaling. Academic Press, San Diego, CA, USA, 386 pp.

Tomich TP, Argumedo A, Baste I, Camac E, Filer C, Garcia K, Garbach K, Geist H, Izac AM, Lebel L, Lee M, Nishi M, Olsson L, Raudsepp-Hearne C, Rawlins M, Scholes R and van Noordwijk M, 2010. Conceptual frameworks for ecosystem assessment: their development, ownership, and use. In: Ecosystem and human well-being: a manual for assessment practitioners. Eds Ash N, Blanco H, Brown C, Garcia K, Henrichs T, Lucas N, Raudsepp-Hearne C, David Simpson R, Scholes R, Tomich T, Vira B and Zurek M. Island Press, Washington DC, USA, 71–113.

Turner MG and Gardner RH, 1991. Quantitative methods in landscape ecology: an introduction. In: Quantitative methods in landscape ecology. Eds Turner MG and Gardner RH. Springer, New York, NY, USA, 4–14.

US EPA (Environmental Protection Agency), 2009. Terms of Environment: Glossary, Abbreviations and Acronyms. Available online: http/www.epa.gov/OCEPAterms/

Vanderwalle M, Sykes MT, Harrison PA, Luck GW, Berry P, Bugter R, Dawson TP, Feld CK, Harrington R, Haslet JR, Hering D, Jones KB, Jongman R, Savorel L, Martins de Silva P, Moora M, Paterson J, Rounsevell MDA, Sandin L, Settele J, Sousa JP and Zobel M, 2008. Review paper on concepts of dynamic ecosystems and their services. Rationalising Biodiversity Conservation in Dynamic Ecosystems (RUBICODE) project, 94 pp. Available online: http://www.rubicode.net/rubicode/outputs.html