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Students' Reasoning about the Future of Disturbed or Protected Ecosystems & the Idea of the 'Balance of Nature'

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Abstract This paper is part of a larger study that aims at highlighting students' interpretations of the idea of the 'Balance of Nature', as well as its use in their reasoning about the future of an ecosystem, in order to subsequently develop a learning environment that might promote a reconsideration of its validity and usefulness. Our focus here is particularly set on whether and how non biology-major students use this idea when making predictions about (a) the future of an ecosystem that is supposed to have suffered a human-driven disturbance, and (b) the future of an ecosystem that is supposed to be protected against such disturbances. Administering a questionnaire of 12 items - 4 of which concern us here - to 61 1st-year educational sciences students at the University of Patras, we traced - among others - their reasoning about (a) the future of three ecosystems (forest, sea, lake), supposed to have suffered different human-driven disturbances (fire, oil spill, new population introduction), and (b) the future of a protected forest ecosystem of a national park. According to our findings, most of the students found it very likely for a disturbed ecosystem to fully recover its initial state - mainly due to a *'recovery process'* or inherent *'recovery mechanisms'* - showing a strong belief in an extremely resilient 'Balance of Nature'. Moreover, most of them appeared to believe that if human-protected, an ecosystem will be in a continuous 'balance', while very few were skeptical enough to claim a non-predictable future for it.

Keywords 'Balance of Nature' · Humans and 'Balance of Nature' · Students' reasoning about nature · Students' predictions about ecosystems

Introduction to the Study

The idea of the 'Balance of Nature' is a long-lasting, well spread assumption about the natural world, which implies a predetermined order and stability attributed either to a divine power or nature itself (Cuddington 2001; Cooper 2001; Kricher 2009). This idea was used

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as an explanatory device for the functioning of nature long before ecology emerged as a scientific discipline and *does* persist even in the context of it (Jelinski 2005) with a rather ambiguous influence on the advancement of the ecological thought. Cuddington (2001) pointed out that the idea of the 'Balance of Nature' restricted the meaning of mathematical equilibrium in population ecology, while Kricher (2009) considers it as the *'most burdensome philosophical baggage'* of ecology.

Although scientifically controversial and strongly criticized as not representative of the natural systems in most of its interpretations (Jansen 1972; Cooper 2001; Cuddington 2001; Kricher 2009), the idea of the 'Balance of Nature' is well established in popular culture (Ladle and Gillson 2008) and dominant in school science (Korfiatis et al. 2004; Jelinski 2005; Westra 2008). Apart from hindering students in advancing their ecological reasoning (Zimmerman and Cuddington 2007), this idea and its underlying assumption that favours purpose over randomness may also interfere with the development of students' evolutionary reasoning - just like the Aristotelian paradigm of a *'directed, purposeful, balanced but static nature'* did with the development of the evolutionary reasoning within the scientific community itself (Kricher 2009). Thus, it seems to provide an interesting framework for contemporary biology education research (Jelemenska and Kattmann 2008; Sander et al. 2006; Zimmerman and Cuddington 2007).

Students have been reported with the idea of the 'balance' as a *'law of nature'* (Engstroem 1981) or as an inherent feature of real ecosystems (Jelemenska and Kattmann 2008; Zimmerman and Cuddington 2007). Moreover, they have been reported with the idea of 'mechanisms' that control the maintenance of the 'natural balance' (Zimmerman and Cuddington 2007), which is actually met within the *'cybernetic view'* of nature that addresses the ecosystem as a machine-like, self-regulated system with strong resilience (Westra 2008).

Attempting to describe these 'mechanisms', students have revealed a *'teeter-totter'* conceptualization of the ecosystem (Westra 2008), according to which the ecosystem's populations are constantly engaged in maintaining the balance through oscillations, just like children do on real, play-ground teeter-totters. The idea is that *'If a population wanders too far to one side, another population counters that move and adjusts accordingly by moving to the other side'* and thus *'the balance persists as long as man does not intervene'* (Westra 2008, p.68).

But how do students actually define the 'Balance of Nature'? Carrying out a qualitative study with interviews from 16–17 year old students of German and Slovakian schools, Sander et al. (2006) traced three different definitions of the 'Balance of Nature' on behalf of their participants. According to these, the 'balance' refers to (a) the well-balanced prey-predator relationships, (b) the hierarchical order among organisms, or (c) the complete cycle of matter.

More interestingly, what actually seemed to underlie *all* three definitions formulated by Sander et al's participants was the idea that the 'balance' ensures the survival of the organisms and thus the *'preservation of life'* itself. Students did *not* appear to regard 'imbalance' as simply a change for the ecosystem, but as a major threat for its own existence. According to Sander et al. (2006), the idea of 'balance' as a 'normal' or 'natural' state may be associated with students' *'orientation towards the visible'*; namely, with their tendency to focus on how nature becomes 'visible' in their everyday perspective. Students may conceive nature as constant, because it may actually appear to be this way in the temporal and spatial perspectives of one's life.

Carrying out a content analysis of both the definitions and the explanations for the 'Balance of Nature' offered by their sample (143 undergraduate, science and non-science majoring students in the USA), Zimmerman and Cuddington (2007) traced a wide range of sometimes *'ambiguous'* or even *'circular'* interpretations, where *both* the 'balance' *and* its causes were described as exactly the same thing (i.e. as the cooperation of species).

In this first study of Zimmerman & Cuddington, the 'Balance of Nature' was mainly defined as the regulation of populations, cooperative survival, species interactions and availability of resources, whereas it was mainly attributed to the absence of disturbance or to nature itself. Thus, it is not surprising that once more the students were reported with the idea of 'balance' as descriptive of real ecosystems. A follow-up survey with 321 undergraduate students - conducted by the same researchers - showed that the findings of the first study may be considered as representative of how the larger educated population thinks about the 'Balance of Nature'.

Considering the above, we were engaged in shedding more light not only on students' reasoning about the idea of the 'Balance of Nature' itself, but also on the use of this idea in students' reasoning strands about the future of disturbed ecosystems, in order to subsequently develop a learning environment that could possibly promote a reconsideration of its validity and usefulness. Our focus in this paper is particularly set on whether and how non biology-major students - and more specifically, students of educational sciences - use the idea of the 'Balance of Nature' when making predictions about (a) the future of an ecosystem that is supposed to have suffered a human-driven disturbance, and (b) the future of an ecosystem that is supposed to be well-protected against human-driven disturbances.

Thus, the questions addressed here are: 'How do non biology-major students make predictions about the future of ecosystems that have suffered human-driven disturbances or are well protected against them?', 'what does the idea of the 'Balance of Nature' invoke in their reasoning?'. In other words, 'how likely do they think a disturbed ecosystem will recover its pre-disturbance state or for a human-protected ecosystem to maintain its current state in the future and how do they warrant their claims?'.

Methods

The present study is located within the qualitative research paradigm. In fact, it is an exploratory case study that attempts to investigate in detail how young people, who have just entered the university in order to become early year educators, may reason about the future of disturbed or protected ecosystems.

The collection of the data was performed by having students fill in a questionnaire rather than give us individual, semi-structured interviews. This methodological choice had merely to do with practical issues, such as time constraints and - more importantly - the need to ensure the anonymity of the participating students so that: (a) they could feel more free to decide whether they would participate or not, and (b) they could be more genuine in their responses as they wouldn't have to worry about any possible consequences on their final grade. Nevertheless, it should be noted that administering a questionnaire instead of conducting face-to-face semi-structured interviews deprived us of the opportunity for a more dynamic interaction with the students, which could have facilitated the in-depth exploration of their reasoning.

The Participants of the Study

The participants of the study were 61 first-year students of the Department of Educational Sciences and Early Childhood Education of the University of Patras who were attending the optional course ‘Essential Concepts of Ecology’, offered by one of the authors. The total number of the students enrolled to the course was 180. The 61 students/future early year educators volunteered to contribute after being informed about the study and the underlying principles of free participation and anonymity.

The participating students (60 female and one male) had actually completed the same curriculum for ecology due to the ‘General Biology’ course they all had to take at the end of the secondary education. In the context of this course, they were presented with the idea of the ‘balance’ in the relationships of the biotic and abiotic components of the ecosystem, as well as with the idea of the ‘regulatory mechanisms’ that preserve this ‘balance’ (Adamantiadou et al. 2007).

The students had also encountered these ideas earlier in their school-years. According to the national biology education curriculum: (a) the 3rd grade high-school students are expected to be able *‘to describe the mechanisms through which the ecosystems maintain their balance using specific examples’,* and (b) the 6th grade primary-school students are expected to get familiar with the idea of *‘balance/auto-regulation’,* which is included in the list of the *‘Essential Concepts for Cross-Curricular Approaches’* in the unit *‘Environment’.*

The Questionnaire

The data collection instrument was a 12-item questionnaire with six fixed-choice items and six open-ended ones, which was developed by drawing upon the questionnaires and findings of Zimmerman and Cuddington (2007) and Sander et al (2006). Before being administered to the informants of the study, the questionnaire was tested with six students who had the same profile as the informants. After filling it in, these students took part in a focus group discussion led by one of the authors and made their comments in order to help us establish ‘face validity’ (Muijs 2004). Finally, the elaborated questionnaire was administered individually to our 61 informants, before any issue that might be related to the target idea was negotiated within the offered course.

The items of the questionnaire were organized in four parts (see ‘Appendix’). These were administered to the students separately. In other words, students had to return their responses to one part of the questionnaire *before* they were given the next one. The whole process of filling in all four parts of the questionnaire lasted approximately 40 min.

Narrowing down to ‘Part D’ which concerns us here, we note that it included four open-ended items. The first 3 of them engaged students in making predictions about the post-disturbance era of three different ecosystems (forest, sea, lake), each supposed to have a specific composition of animal and plant populations and suffer a different human-driven disturbance, such as:

(a) a fire that caused the total destruction of the forest (Question D1: ‘forest fire’ scenario),
(b) an oil spill that caused changes in the size of the sea populations without any eliminations and it was finally removed (Question D2: ‘oil spill’ scenario), and
(c) an introduction of a new fish population in a lake that caused changes in the size of the lake populations without any eliminations, and finally it was removed from the lake because of a virus that was highly pathogenic for the specific population but harmless for all the others (Question D3: ‘new fish’ scenario).

As already shown, the types of the human-driven disturbances we used, covered a range from a 'natural-like' disturbance (QD3) to a pollution-based one where human correcting action *did* take place (QD2), and finally to a totally destructive one with no human correcting action at all. In all three hypothetical scenarios, students were required to predict how the ecosystem might look like concerning its animal and plant populations, when time passed ('forest fire' scenario) or the disturbing factor was removed ('oil spill' & 'new fish' scenarios); that is, how each ecosystem might look like compared to how it initially did?

On the contrary, the 4th item of 'Part D' engaged students in making predictions about the future of a forest ecosystem that was supposed to have a specific composition of animal and plant populations and lie within a well-protected 'national park', where human-disturbances were not allowed and scientific monitoring was taking place regularly: how this human-protected ecosystem might look like as time passed, compared to how it initially did? (Question D4: 'national park' scenario).

The Overview of the Analytic Procedure

The 61 filled-in questionnaires were transcribed to Word-files and prepared for coding within the qualitative analysis software 'NVivo'. Coding the prepared questionnaires and more specifically the responses to the four open-ended questions of 'Part D' that concern us here, one of the authors came up with of a series of 'categories' regarding (a) students' claims about the future of the ecosystems in question, and (b) students' warrants for these claims. These data-based 'categories' were organized in a 'coding scheme', a representative part of which - the one that concerns the oil spill scenario (Question D2) - is presented in Fig. 1.

The developed 'coding scheme' was then applied for independent coding by the other author as well. So, all the responses with regard to 'Part D' were coded by both authors. Finally, the Cohen's kappa for the inter-rater reliability was estimated to 0.92.

Findings

The analysis of our data regarding students' reasoning about (I) the future of an ecosystem that has suffered a human-driven disturbance, and (II) the future of an ecosystem that is well-protected against such disturbances, showed the following.

Students' Reasoning About the Post-disturbance Era of an Ecosystem

The students came up with three categories of predictions about the future of the disturbed ecosystems of the different scenarios. More specifically, they claimed that these would (a) fully recover their initial state - (i) definitely or (ii) at least possibly - and look exactly as they initially did, (b) partially recover their initial state and look similar to how they initially did but *not* exactly the same, and (c) suffer a permanent collapse (Fig. 2).

The Prediction of 'Full Recovery of the Initial State'

As shown in Fig. 2, the students came up with the prediction that the disturbed forest-, sea-, or lake-ecosystem of each of the three different scenarios would fully recover its initial state (a) *'definitely'* (20/61 or 32.8%, 27/61 or 44.3%, 46/61 or 75.4%), or (b) *'possibly'* (4/61 or 6.6%, 9/61 or 14.7%, 3/61 or 4.9%), and look exactly as it did before

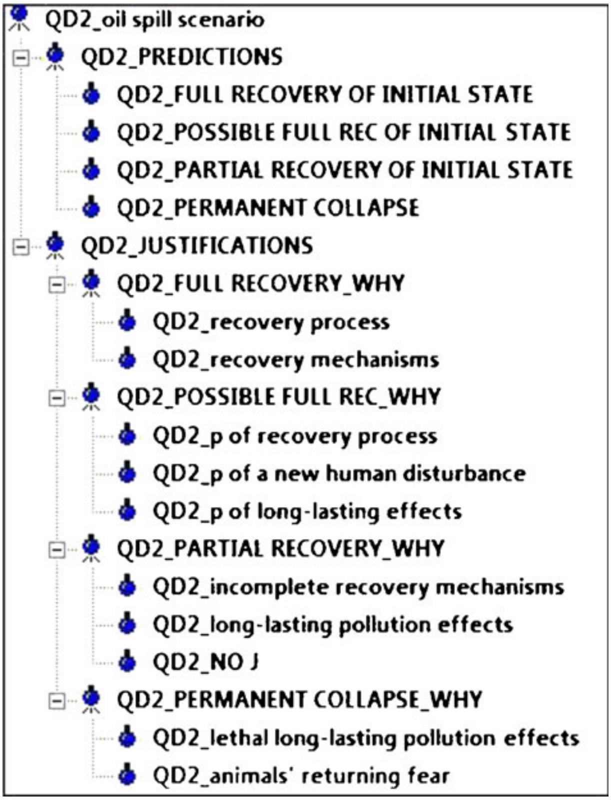


Fig. 1 Part of the coding scheme ('oil spill' scenario)

the forest fire, the oil spill or the introduction of the new fish population, correspondingly. In students' own words:

(a) '*It will take much time for the forest to recover, but I think that it will finally become the same as before*'; '*The balance in the sea area will recover some years after*

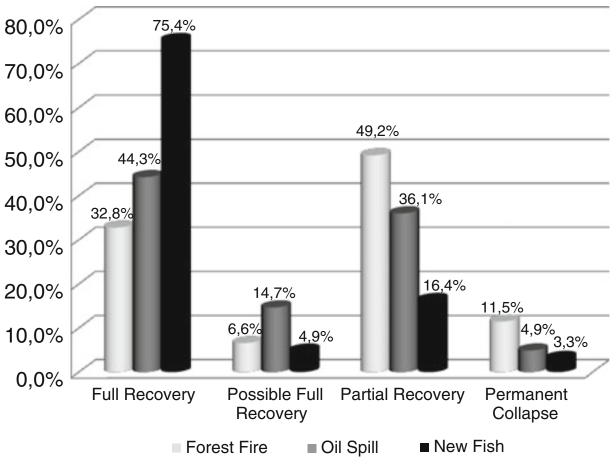


Fig. 2 Categories of students' predictions for the scenarios 1–3

cleaning the oil spill… the picture will be as it was before the accident'; *'Since the new population which caused all these changes in the lake will get eliminated by the virus, the lake will re-gain its initial picture'.*

(b) *'After many years, the forest will probably have the same picture as before if something similar (i.e. another fire) does not happen again'; 'If the area is cleaned from the oil, some years later the ecosystem will probably have the same picture as before'; 'If the fish population is killed by the virus, the lake will probably return slowly to its initial state'.*

But how did the students justify the full recovery prediction about the ecosystems of the three scenarios? Starting from the prediction of a *definite* full recovery, we summarize the categories of their justifications in Fig. 3. More specifically, claiming a full recovery of the ecosystem's initial state was justified by drawing upon a *'recovery process'* that had to do (a) with the time-consuming and sometimes human-based regeneration of the plants, which sets the scene for the increase of the animals of the recovering forest; the plant regeneration was sometimes associated with the *'decomposition'* of the fire-produced dead organic matter and the *'enrichment of the soil with essential nutrients'* (12/61 students or 19.7%), (b) with a gradual increase in the size of the plant and then the animal populations of the recovering sea area; this was sometimes associated with the fact that the disturbance did *not* result in the *'elimination'* of any population (21/61 informants or 34.4%), and (c) with the removal of the disturbing factor (the new fish population) that triggers the restoration of the initial balance of the lake; this was also associated sometimes with the fact that no *'eliminations'* took place (44/61 informants or 72.2%). In students' own words:

(a) *'Years later, the forest will return to its initial state. The soil will be fertile due to the ash and the seeds from the burnt plants will start germinating. Then some herbivores will come from nearby areas and manage to thrive, since there will be food for them and no predators against them. The carnivores will follow and they will increase quite soon, since they will find abundant food. Finally, the size of the plant and animal populations will be stabilized at their previous point'; 'The forest will be able to recover and finally re-establish its initial state after many years, because the fire created much dead organic matter and the decomposers of the ecosystem will make it available first for the new plants by adding to the nutrients of the soil'.*

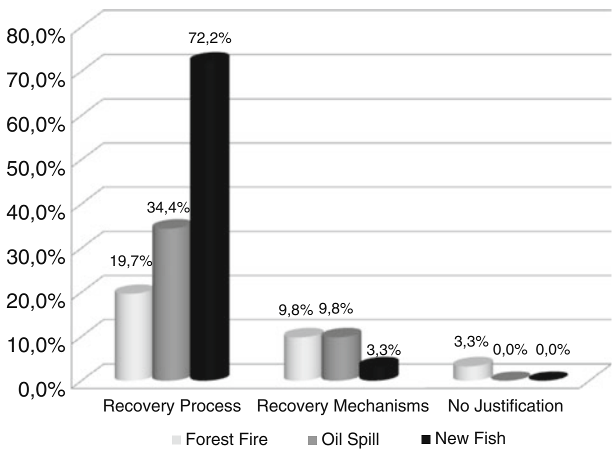


Fig. 3 Categories of students' justifications for the full recovery prediction

(b) *'After the removal of the oil spill, phytoplankton and then zooplankton will start increasing their numbers and finally provide enough food for the small fish. These will also start increasing in turn and provide food for the big fish and the sea birds. This way the numbers of the different populations will finally stabilize at their previous point and thus the ecosystem will return to its initial state'; 'Since the populations got smaller but none of them got totally extinct, they will start increasing again after the removal of the oil spill, until the ecosystem returns to its initial state some years later'.*

(c) *'The new fish was the factor that caused the destabilization of the food chain, the creation of new inter-population relationships and a new stabilization of the food chain. When this factor is removed, the ecosystem will follow the reverse course and it will return to its initial state and recover the balance of the initial inter-population relationships'; 'When the new fish are gone, the populations that had decreased because of them will now increase, and those that had increased will now decrease. I think that the system will return to its initial state and re-gain its balance'; 'Some years later, the ecosystem will re-establish its initial state, because every initial population is still present in the lake after the new fish are gone and their changed sizes will start changing again towards the initial ones'.*

Although this type of justification for the full recovery prediction seems to imply the idea of *'recovery mechanisms',* we *did* trace another type which makes an explicit use of it. More specifically, some informants grounded this prediction within the three scenarios by *explicitly* drawing upon the function of the ecosystem's *'recovery mechanisms'* which enable the *'restoration of the system's balance'* ((a) 'forest fire' scenario: 6/61 or 9.8%, (b) 'oil spill' scenario: 6/61 or 9.8%, (c) 'new fish' scenario: 2/61 or 3.3%). In students' own words:

(a) *'The forest will return to its initial state, because every forest has mechanisms of auto-recovery which regenerate it after a destructive fire'.*

(b) *'I think that some years after the removal of the oil spill, the sea area will finally become as it was before the accident, because the recovery mechanisms of the sea ecosystem will bring it back to where it was'.*

(c) *'Every ecosystem has mechanisms that contribute to the maintenance of its balance. These will bring the disturbed ecosystem of the lake back to its initial state if the cause of the disturbance is removed'.*

As shown in Fig. 4, claiming a *possible* full recovery of the ecosystem's initial state was justified by appealing (a) to the *'possibility of a recovery process'* ('oil spill' & 'new fish' scenarios: 5/61 or 8.2% & 2/61 or 3.3%), (b) to the *'possibility of long-lasting effects'* for the ecosystem ('oil spill' & 'new fish' scenarios:3/61 or 4.9% & 1/61 or 1.6%), and (c) to the *'the possibility of a new human-driven disturbance'* at the recovering ecosystem ('forest fire' and 'oil spill' scenarios: 4/61 or 6.6% & 1/61 or 1.6%). In students' own words:

(a) *'The ecosystem will possibly return to its initial state, because after the removal of the oil spill the phytoplankton may possibly start increasing and this may possibly lead to the increase of the other populations up to their previous size';' If the new fish did not stay in the lake for a very long time before they were killed by the virus, it is possible that the lake will return to its initial state, because the populations that got smaller will probably start increasing and those that got bigger will probably start decreasing'.*

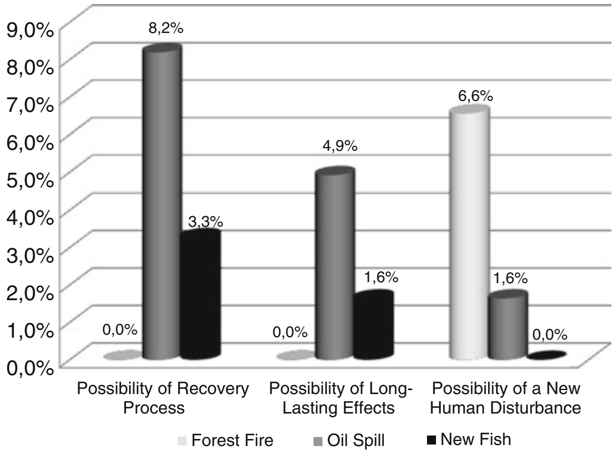


Fig. 4 Categories of students' justifications for the possible full recovery prediction

(b) *'The ecosystem will probably go back to where it was and probably not... the balance of nature has definitely been disturbed before the removal of the oil spill ... it is possible that the damage of the food chain because of the oil pollution will be very hard to repair'; 'If the new population lived in the lake for a long time before its elimination by the virus, the food chain of the lake might have been significantly changed and it will be difficult for the ecosystem to return to its initial state… it will probably make it or not'.*

(c) *'The forest will possibly re-gain its initial state many years later, if another similar disturbance does not happen again. For instance, a new fire or grazing or building'; 'It is possible for the sea ecosystem to return to its initial state, provided that it will no longer be polluted'.*

The Prediction of 'Partial Recovery of the Initial State'

As shown in Fig. 2, students came up with the prediction that the disturbed ecosystems of the three different scenarios would recover their initial state only partially, and thus they would look similarly but not exactly the same as they did before the forest fire (30/61 or 49.2%), the oil spill (22/61 or 36.1%) and the introduction of the new fish population (10/61 or 16.4%) correspondingly.

Comparing the new, partially recovered state of the forest-, sea- and lake-ecosystem with the initial one, the students described the differences in terms of (a)*'different number of species'*('forest fire' scenario: 17/61 or 27.9%, 'oil spill' scenario: 7/61 or 11.5%, 'new fish' scenario: 3/61 or 4.9%*),* (b) '*different population sizes'* ('oil spill' & 'new fish' scenarios: 11/61 or 18%, 4/61 or 6.5%*)*, and (c) both of the above mentioned ('forest fire' scenario: 11/61 or 18%, 'oil spill' scenario: 4/61 or 6.6%, 'new fish' scenario: 3/61 or 4.9%), or (d) they did not indicate any specific differences at all ('forest fire' scenario: 2/61 or 3.3%). In students' own words:

(a) *'The forest will not have the variety of the different species of animals it had before the fire'; 'There will be an obvious decrease in the number of species in this sea area...we will not find all the organisms we found before'; 'When the fish are eliminated, the lake populations which fed upon them will be eliminated as well, and the ecosystem will now have less populations than before the disturbance'.*

(b) *'Some years later, the size of the populations will increase, but still it will not be as large as before'; 'The populations will not return exactly to the same size they had before, so the ecosystem won't be exactly the same'.*
(c) *'The populations of forest plant and animals will be smaller and consist of less demanding species'; 'The number of the different species and the number of the organisms that make up their populations will be smaller'; 'The populations which fed upon the fish will even be eliminated after some time, while those being the fish food will now increase'.*
(d) *'Some years later, the forest will start to regenerate… first it will start 'blooming' and then animals will start gathering'.*

The partial recovery prediction was left unwarranted by 8/61 or 13.1% of the students in the 'oil spill' scenario. Figure 5 summarizes the categories of students' justifications for this prediction. More specifically, in order to justify the prediction of the partial recovery students drew (a) upon the idea of an *'incomplete'* - sometimes human-based - *'recovery process'* ('forest fire' scenario: 5/61 or 8.2%), and (b) upon the idea of *'incomplete recovery mechanisms'* which take over but do *not* lead the ecosystem *all* the way back; this was sometimes associated explicitly with the idea that *'full recovery after a human-driven disturbance is difficult or even impossible'* ('forest fire' scenario: 3/61 or 4.9%, 'oil spill' scenario: 5/61 or 8.2%, 'new fish' scenario: 3/61 or 4.9%). In students' own words:

(a) *'Some seeds could have been into the soil before the fire and these will give some plants in the future … and then some animals will be gathered, too'.*
(b) *'Nature has recovery mechanisms and so, some years later, the forest will recover but it will not be exactly the same. There will be changes in the populations that will be present and so the new situation will be only similar to the initial'; 'The changes in the size of the lake populations after the introduction of the new fish will destroy the lake balance and it will be difficult for the lake to restore this balance after the elimination of the new fish'.*

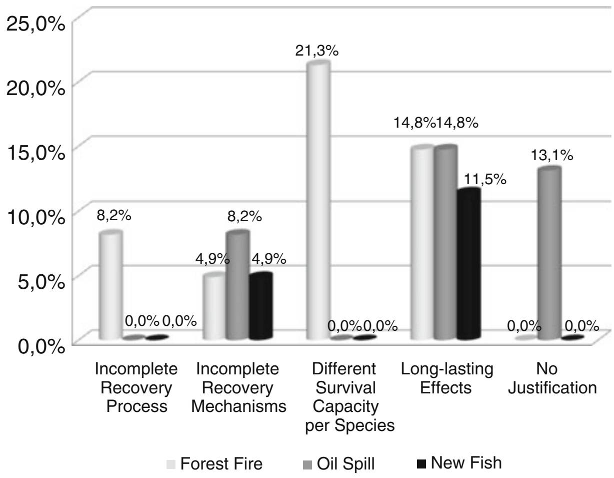
Moreover, students who predicted that the ecosystem would *partially* - and not fully - recover its initial state and have less species and/or smaller populations, appealed to the idea that some species would be disfavored compared to others because of *'differences in their survival capacity'* ('forest fire' scenario: 13/61 or 21.3%): (a) they could not actually *'survive the disturbance'*, and (b) they could not *'fulfil their complex survival needs'* after the disturbance (Fig. 5). In students' own words:

(a) *'Snails and insects could survive by hiding, but squirrels or deer could not'.*
(b) *'Only the low-demanding animals will be able to thrive. The forest ecosystem won't be able to support animals with high demands for their survival'.*

Finally, the partial recovery prediction was also grounded upon the idea of *'long-lasting effects'* such as (a) a permanent disturbance of the food chain ('forest fire' & 'new fish' scenarios: 9/61 or 14.8% & 7/61 or 11.5%) and (b) a degradation of the polluted habitat that cannot be stopped with the removal of the factor that triggered it in the first place, or a transfer of the pollutant along the food chain ('oil spill' scenario: 9/61 or 14.8%) (Fig. 5). In students' own words:

(a) *'The big carnivores will not be able to find food, while the insects or the small herbivores will be'; 'The food relationships between the organisms of the lake have already been changed and the previous balance of the food chain will not be fully restored after the death of the fish'.*

Fig. 5 Categories of students' justifications for the partial recovery prediction



(b) *'Despite the removal of the oil spill, the organisms will still have to deal with the effects of the pollution. The polluted area has become a hard place for their survival and reproduction, meaning that the ecosystem will not be able to return exactly where it was'; 'The oil has penetrated the organisms and been transferred through the food chain. So, even after its removal from the sea, the organisms will still have problems with it. Some populations will possibly be exterminated at the end and the ecosystem will not manage to fully recover its initial state'.*

The Prediction of 'Permanent Collapse'

As shown in Fig. 2, some students came up with the prediction that the disturbed ecosystems would suffer a '*permanent collapse*' ('forest fire' scenario: 7/61 or 11.5%, 'oil spill' scenario: 3/61 or 4.9%, 'new fish' scenario: 2/61 or 3.3%). According to this prediction, the destruction caused by the fire, the oil spill or the introduction of a new fish population in the lake would be permanent and thus there would be - definitely or at least *most* likely - no chance for the ecosystem in question to recover its initial state on its own or reach any other living state ever again. In students own words:

- *'If the forest is left on its own after the disastrous fire and humans do not plant any trees, it will remain a black and empty space with no life at all'; 'In this area there will be no plant-life or animal-life again… the sea-ecosystem will collapse'; 'The most likely case is that the ecosystem of the lake will be totally destroyed'.*

As shown in Fig. 6, the permanent collapse prediction was grounded (a) upon the idea of the *'difficulty of the recovery process'* which seems to be considered as almost impossible especially if no human help is provided to nature after the human-driven disturbance ('forest fire' scenario: 7/61 or 11.5%, 'new fish' scenario: 2/61 or 3,3%), (b) upon the idea of *'lethal long-lasting effects'* of the disturbing factor, such as the permanent damage of the food chain ('oil spill' scenario: 2/61 or 3.3%), and (c) upon the idea of the disturbance-driven *'fear'* of the sea animals to *'return'* to their habitat ('oil spill' scenario: 1/61 or 1.6%). In students' own words:

(a) *'If the forest is left on its own after the disastrous fire without any human intervention that could help it, then it will never be the same again… everything is destroyed …*

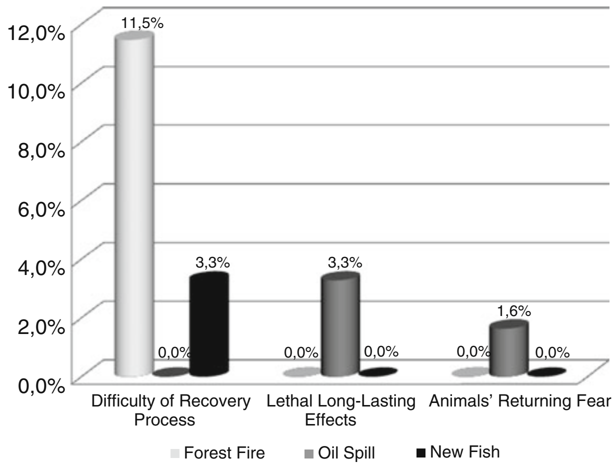


Fig. 6 Categories of students' justifications for the permanent collapse prediction

nothing can grow and live there'; *'The most likely is that the ecosystem will be destroyed for ever because the balance has already been broken and it will be very difficult for the ecosystem to re-establish it'*.

(b) *'The organisms will finally be eliminated because of the oil spill, even if it is eventually removed from the sea. At the end, even the few left micro-organisms which form the basis of the food chain will be killed because of the oil and thus the ecosystem will collapse: no plant or animal life will be there again'*

(c) *'The sea ecosystem of the area will be destroyed forever, as the animals will be afraid of returning because of the disaster they had experienced when the oil spill was released in their habitat'*.

Students' Reasoning about the Future of a Human-protected Ecosystem

Our informants came up with three categories of predictions. More specifically, they claimed that, some years later, the protected ecosystem of the hypothetical 'national park' (a) would definitely or at least possibly have exactly the same picture as the one described in the scenario, (b) would have a different picture, and (c) would have a picture which cannot actually be predicted. Moreover, 2/61 informants (3.3%) did not provide any prediction at all within this scenario (Fig. 7).

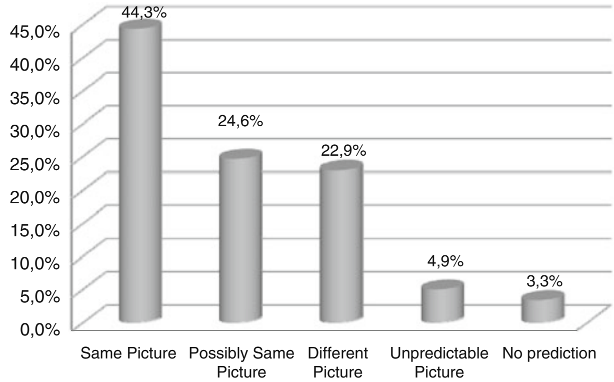
The Prediction of the 'Same Picture'

This was the most popular prediction, since it was provided by 42/61 or 68.9% of the participating students. More specifically, 27/61 or 44.3% claimed that the protected ecosystem of the national park would *'definitely*' remain exactly the same, while 15/61 or 24.6% claimed that this would be *'possibly'* the case.

As shown in Fig. 8, the most popular prediction of the *'definitely same picture'* was grounded upon the idea that *'nature can be self-regulated in the absence of human-driven disturbances'* (27/61 or 44.3%). The non-disturbing or even assisting role of humans combined with nature's tendency to remain balanced is underlying students' argument for the same picture. In their own words:

- *'If humans do not disturb the forest and leave nature's mechanisms to take over, nature will do its job and accomplish the maintenance of the balance'*; *'The balance will be*

Fig. 7 Categories of students' predictions in the 'national park' scenario



maintained through the relationships of the organisms, since there will be no disturbance by the humans'; '*Since the ecosystem will not be disturbed by the humans and will be constantly monitored by experts, they will be able to record any possible change in its balance and help the ecosystem in correcting it and remaining the same'; 'The ecosystem will maintain its balance as time passes, since it will not be disturbed by the humans. And in case that the balance is influenced by any changes in the environmental conditions, it can actually be restored through the recovery mechanisms of the nature'.*

Moreover, those who predicted that the future picture of the protected ecosystem would *possibly* remain the same, did it by appealing (a) to the *'possibility of environmental changes'* (14/61 or 23%), and (b) to the *'possibility of changes in population sizes'* because of the food relationships (1/61 or 1.6%) (Fig. 8). In students' own words:

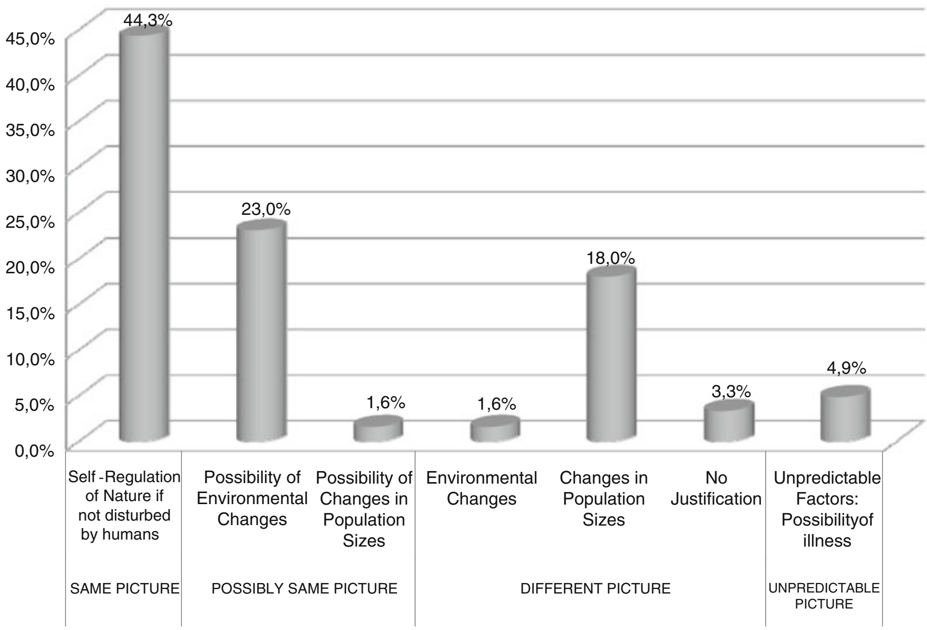


Fig. 8 Categories of students' justifications in the 'national park' scenario

(a) *'The future picture could only possibly be the same, because the balance may be disturbed by environmental factors like floods or drought'.*
(b) *'In the future, the forest could possibly look like it did in the past. But we cannot be absolutely sure, because there is a chance of changes in the populations' sizes since they feed on each other'.*

The Prediction of a 'Different Picture'

This prediction was provided by 14/61 informants (22.9%). For 9 of them (14.7%) the difference of the future ecosystem would be *'bigger populations'*, for 3 (4.9%) the difference would be *'smaller populations'*, and for 2 (3.2%) the difference would be *'both bigger and smaller'* populations.

As shown in Fig. 8, claiming that the future picture of the protected ecosystem would be *'different'* was justified upon (a) the idea of '*environmental changes',* now considered as a *fact* rather than as a possibility (1/61 or 1.6%), and (b) the idea of *'changes in population sizes'* (11/61 or 18%) now considered as a *fact* which was attributed either (1) to the food relationships, or (2) to the ideal conditions for population growth due to the absence of human disturbances. In students' own words:

(a) *'The future picture of the forest will definitely be different because - even though there will be no human disturbances - the changing environmental conditions will influence the organisms more or less and they will create new needs in the forest and a whole new balance'.*
(b) (1) *'Some plant and animal populations will get smaller since they are eaten by others'*; *'Some populations will get smaller and some others will get bigger through the food relationships'.*
(2) *'Since the forest lies in a well-protected area without any disturbances by humans, there will definitely be an increase in the size of both the plant and animal populations. This is expected beyond any doubt, because, since the forest is undisturbed by the humans, it will be in an absolute balance which will be maintained and enhanced'.*

The Prediction of an 'Unpredictable Picture'

This prediction was provided by only 3/61 informants (4.9%). In their own words: *'Even though the forest is under human control, we cannot really make any predictions about what will happen to it'.*

According to Fig. 8, claiming that the future picture of the protected ecosystem could not actually be predicted was justified upon the idea of *'unpredictable factors'* and specifically a *'possible illness'* that could cause major changes in the ecosystem at any time. In students' own words: *'Human protection cannot actually isolate the ecosystem from possible threatening factors, such as for instance a virus which could be transferred through the water or the air and attack the animal populations of the protected ecosystem any time'.*

Discussion

Our informants found it very likely for a disturbed ecosystem to fully recover its initial state. In fact, the full recovery prediction was the most popular, except for the 'forest fire' scenario where the partial recovery prediction was provided more often. In this scenario, where the disturbance was supposed to be absolutely disastrous for the ecosystem, the - still quite frequent - prediction of full recovery was explicitly linked with *'time'*. Measured in several years or even decades after the fire, time was almost always highlighted as an essential prerequisite for it. The full recovery prediction reached its highest frequency in the case of the milder or more 'natural-like' disturbance of the 'new fish' scenario.

Claiming that our informants hold a rather strong belief in the idea of a highly resilient 'balance' within the ecosystems may be enhanced further by looking at how they mainly justified their full recovery prediction. The most frequent ways were (a) by appealing to a *'recovery process'* that restores the initial 'balance' either by starting from the increase of specific plants which sets the scene for the increase of specific animals ('forest fire' & 'oil spill' scenarios), or by re-setting the population sizes at their initial values after the removal of the disturbing factor ('new fish' scenario), and (b) by appealing to *'recovery mechanisms'* as an inherent feature of the ecosystem; namely, as something that is always at the ecosystem's disposal to lead it back to its initial balanced state.

It is worth noticing that in the case of the 'natural-like' disturbance of the 'new fish' scenario, the recovery process of the ecosystem was quite often described similarly to the 'recovery' process of a platform scale being in disequilibrium because of the addition of an extra weight on it; in other words, similarly to the process of removing this extra weight. This may be considered as another, more simplistic version of the 'teeter-totter' view of the ecosystem (Westra 2008), since it highlights the ecosystem's potential to re-establish its previous balance as long as the factor that disturbed it goes away.

Indications of a more 'dynamic' view of the ecosystem on behalf of the students could possibly be found in the more skeptic prediction of the partial recovery and the ways of its grounding. In fact, recognizing that it is more likely for a disturbed ecosystem to establish a new similar state in the future rather than actually return to its initial one, *might* be close to the idea that *'nature has a range of ways to be'* (Picket et al. 1992) and its past is rather irreversible since *'change is followed by chance'* (Westra 2008).

Nevertheless, a closer look at students' justifications reveals that what actually led them to the prediction of the partial recovery was *not* the conceptualization of the ecosystem as flexible enough for accommodating the changes of its dynamics in alternatives ways varying in space and time (De Ruiter et al. 2005), but the identification of significant constraints in the re-establishment of its initial state. In other words, the ecosystem was predicted to reach a new state as it could *not* return to its initial one because of constraints; for instance, the degradation of the disturbed habitat and the different capacities of the different species to deal with it, or the ineffectiveness of the recovery mechanisms to take the ecosystem all the way back.

Thus, our findings in regard with students' reasoning about the future of disturbed ecosystems *did* show a strong belief in the idea that nature has appropriate 'balanced' states where it should always return. This is actually in line with what has been reported by previous studies (Engstroem 1981; Jelemenska and Kattmann 2008; Sander et al. 2006; Zimmerman and Cuddington 2007). Moreover, students' inability to recognize that a change in the ecosystem may result in different, chance-influenced trajectories may be considered as the ecosystem-bound manifestation of students' broader, inaccurate assumption about randomness and purpose in biological processes.

As pointed out by Garvin-Doxas and Klymkowsky (2008), this deeply rooted assumption according to which randomness *cannot* be compatible with the highly efficient biological systems whereas purpose *can* be, may hinder students' understanding about several aspects of the biological world. In fact, students' difficulty to cope with the idea of randomness has been reported as interfering with their understanding in several contexts besides the ecological one that concerns us here, since random events *do* underlie a wide range of different-level biological processes. Such contexts appear to be the ones of genetics, molecular biology and evolution (Klymkowsky and Garvin-Doxas 2008; Mead and Scott 2010).

With regard to evolution in particular, rejecting the role of randomness and assigning purpose to the evolutionary process seems to lead students to the misconception of a directed, need-driven evolution via purposeful change (Samarapungavan and Wiers 1997; Alters and Nelson 2002; Passmore and Stewart 2002; Banet and Ayuso 2003; Kampourakis and Zogza 2008). So, challenging the 'non randomness-but-purpose' assumption on the level of the ecosystem might be rather important for the advancement of students' reasoning about *both* the ecosystem's dynamics *and* the evolutionary history of its biotic part.

Moving on to students' reasoning about the future of a human-protected ecosystem, we should point out the emergence of a strong belief in the role of humans regarding the 'balance' of nature. The most frequent prediction was that when human-protected, nature cannot but be in a continuous 'balance', since (a) human-driven disturbances are absent, and (b) both human- *and* nature-driven recovery of the recorded natural disturbances are available. In other words, students appeared to believe that nature is self-regulated as long as humans do not cause any disturbances.

It is worth noticing that the belief in the significance of the human role, in terms of not causing as well as restoring disturbances, was also indicated in students' reasoning about the disturbed ecosystems before the scenario of the 'national park'. In fact, in the 'forest fire' scenario, (a) the possibility of a new *human-driven* disturbance during the recovery process triggered the prediction of a *merely* 'possible' full recovery, rather than a certain one, and (b) the lack of *human* contribution after the disturbance triggered the prediction of a permanent collapse.

Going back to students' reasoning about the human-protected ecosystem of the 'national park', we note that the strong belief in the human control seemed to underlie *even* the predictions about a future ecosystem with a 'possibly same' or a 'different' picture compared to the current one. Although these predictions *might* have revealed a less human-dependent conceptualization of the ecosystem, this was *not* actually the case. For instance, the 'different' picture was mainly attributed to the *fact* that the populations would thrive and become more abundant in the future, since the function of the ecosystem under the *human* control could not but be absolutely ideal.

Despite this rather dominant belief in the power of humans, we *did* locate some *traces* of uncertainty about the future of the human-protected ecosystem as well. A very small number of students (3/61) *did* claim that the future picture of the 'national park' could *not* actually be predicted. The factor they all drew upon as capable of changing the scene at any time was the possibility of a viral illness, something they actually encountered in a previous scenario. So, it seems plausible that the already extremely low frequency of this potentially promising prediction might be even lower if this wasn't the case.

In conclusion, students need to be supported in reconsidering (a) their 'teeter-totter' conceptualization of the ecosystem that includes the idea of a highly resilient 'balanced' state to which the ecosystem tends to return after the removal of the disturbing factor or after the counter-balancing of the changes that the disturbing factor has caused, and (b) their strong belief in the human control over the maintenance of this desired 'balance'.

Moving from the idea of the 'balance' of natural systems - where *humans* have a significant control - to the idea of a constant 'flux' - where *chance* becomes rather significant - *does* require from students to deal with their serious difficulties in considering randomness as an inherent element of the ecological processes and finally view ecosystems as flexible structures; namely, as structures that may accommodate the changes in their dynamics in many alternative and not easily predictable ways.

In fact, moving to this highly dynamic view of the ecosystem might be paralleled with adopting the rather ingenious metaphor of the 'Jenga-game' - that has been introduced by De Ruiter et al (2005) and discussed by Westra (2008) - in order to replace the well spread metaphor of the 'teeter-totter'. When playing Jenga, it is really difficult to predict which pieces will be of key importance for the stability of the Jenga-structure that is undergoing a continuous change. Moving a specific piece at a specific moment of the game may influence the stability of the structure in a totally different way than it might have done in another moment. Similarly, the effects of removing or adding populations even in the same bio-community may be very difficult to predict since these effects may vary significantly in time.

It is rather clear that grasping the uncertainty of the course of nature and the variety of factors that may influence this course, as well as recognizing the ineffectiveness of humans to actually keep nature in certain states, is a particularly demanding task for the students. Nevertheless, it *does* seem to be absolutely worth trying, since currently valid scientific knowledge and informed decisions about nature can be grounded upon it. Systems thinking as well as modeling within appropriate, computer-supported learning environments may contribute to this task, as Westra et al (2008) have already suggested.

Finally, it is worth noticing that familiarizing students with the shift from the idea of the 'Balance of Nature' to the idea of the 'Flux of Nature' within the scientific community itself, might help them reach a better understanding of the nature of scientific knowledge as a constantly negotiated and re-shaped human interpretation of how nature works. In an era where scientific research affects our everyday life more and more, engaging young people in challenging the common view of science as the 'absolute truth' seems to be worth trying as well.

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Appendix: The Questionnaire

Part A

QA1: What do you think that is meant by the phrase the 'Balance of Nature'? Please, explain as much as you can.

QA2: How do you think that the 'Balance of Nature' emerges? In other words, what are the factors that lead to the 'Balance of Nature' according to you? Please, explain as much as you can.

Part B

QB1: What do you think is meant by the phrase the 'Balance of Nature'? Please, read the following statements and indicate the two that correspond the most to your own definition by writing number '1' next to your first choice and number '2' next to your second one.

- Recycling: continuous availability of nutrients
- Good functioning of the food chain: continuous availability of food
- Harmonious co-existence of the organisms
- Balanced prey-predator relationships
- Almost equal birth and death rates in a population
- Maintenance of the size of different populations within limits
- Possibility of the return of the ecosystem to its initial state after a disturbance

QB2: How do you think that the 'Balance of Nature' emerges? In other words, which factors do you think lead to the 'Balance of Nature'? Please, read the following statements and indicate the two that correspond the most to your own explanation about how the 'Balance of Nature' emerges by writing number '1' next to your first choice and number '2' next to your second one.

- Nature
- God
- Absence of disturbance
- Relationships between the organisms
- Relationships between the organisms and their environment
- Mechanisms that ensure the return of the ecosystem to its initial state after a disturbance

Part C

QC1: 'The ecosystems reach balance when there are not any human interventions such as i.e. agricultural activities or urban sprawl'. This is valid:
(A) Always (B) Usually (C) Sometimes (D) Rarely (E) Never

QC2: 'The ecosystems return to balance when the human interventions that caused the disturbance of the balance stop'. This is valid:
(A) Always (B) Usually (C) Sometimes (D) Rarely (E) Never

QC3: 'The ecosystems reach balance when there are no any environmental disturbances such as i.e. drought or floods'. This is valid:
(A) Always (B) Usually (C) Sometimes (D) Rarely (E) Never

QC4: The ecosystems return to balance when the environmental disturbances that caused the disturbance of the balance stop'. This is valid:
(A) Always (B) Usually (C) Sometimes (D) Rarely (E) Never

Part D

QD1 **('Forest fire' scenario):** Suppose that a certain forest hosts plant populations of pines, fir trees, myrtles, poppies and lavenders, and animal populations of deer, hedgehogs, squirrels, owls, snails and insects. This forest suffers a fire that destroys everything. After this, the forest is left on its own. How do you think it will look like some years later compared to how it initially did according to the given description?

QD2 **('Oil spill' scenario):** Suppose that an oil tanker sinks in the Baltic Sea and a huge amount of oil is released. The oil spill spreads in a sea area that hosts many different populations of phytoplankton (microscopic plants of various species) and zooplankton (microscopic animals of various species), small fishes (sardines & herrings), big fishes (tunas & salmons), and sea birds (seagulls & cormorants). This results in a decrease of these populations' size. Sometime later, the oil spill is totally removed from the sea area. How do you think this sea area will look like some years later compared to how it initially did according to the given description?

QD3 **('New fish' scenario):** Suppose that a certain lake, which is situated near a small city, hosts populations of phytoplankton and zooplankton (microscopic plants and animals of various species), plants (water-lilies & canes), fishes (pilchards & trout) and birds (ducks & cranes). The city council decides to add in this lake a new fish population with commercial value (cyprinids). The introduction of this new fish population changes the situation within the lake: some populations decrease and some others increase in size. Sometime later, the new fish population is attacked by a virus which is lethal only for this, while it is completely harmless for all the other populations in the lake. As a consequence, the new fish population dies off. How do you think this lake will look some years later compared to how it initially did according to the given description?

QD4 **('National park' scenario):** A 'national park' - namely a totally protected area where special guards make sure that no human activity takes place - hosts plant populations of pines, fir trees and oak trees, as well as animal populations of deer, ferrets, bears, eagles, hawks, snakes, and turtles. The populations' sizes are regularly monitored by the scientific team of the park, which studies their course in time. How do you think this human-protected area will look some years later compared to how it initially did according to the given description?

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