Volume 2 2016

Articles in this volume

- Dimitris Gounaridis, Anastasios Apostolou, Maria Riga, Petros Moustos, Konstantina Bika, Danai Kontou & Sotiris Koukoulas, *Change detection of forests and semi-natural areas in Greece for the period 1990-2010*, pp. 1-10.
- Yiannis G. Matsinos, Aggelos Tsaligopoulos & Chris Economou, *The interdisciplinary Development of the Term "Soundscape"; Tracing its Ecological Roots*, pp. 11-23.
- Lies de Puydt, Anika Gladytz & Leena Karrasch, *Developing sustainable coastal areas: A comparison between the Netherlands and the United Kingdom*, pp. 24-55.

Published by: Department of Environment, University of the Aegean, 81100, Mytilene, Greece

ISSN: 2241-9829

Website: http://www.env.aegean.gr/aejes/

Editors-In-Chief

Editorial Board

Editorial Board (continued)

Change detection of forests and semi-natural areas in Greece for the period 1990-2010

Dimitris Gounaridis, Anastasios Apostolou, Maria Riga, Petros Moustos, Konstantina Bika, Danai Kontou & Sotiris Koukoulas

A U T H O R S I N F O

Dimitris Gounaridis* is a PhD candidate in the Department of Geography, University of the Aegean (DoG, UoA), Greece.

Anastasios Apostolou is a PhD candidate in DoG, UoA, GR.

Maria Riga, Petros Moustos and Danai Kontou are undergraduate students in the DoG, UoA, GR.

Konstantina Mpika is an MSc student in Geography and Applied Geo-informatics in the DoG, UoA, GR.

Sotiris Koukoulas is an Assistant Professor in the DoG, UoA, GR.

**email*:
gounaridis.d@geo.aegean.gr

A B S T R A C T

Changes in composition and spatial distribution of forests affect directly and indirectly fundamental ecosystem functions. The direct and underlying factors of changes are numerous and interact at various scales. Thus, spatial information of forest cover and its associated changes are essential. Modern tools like geoinformatics and remote sensing allow the systematic monitoring and evaluation of forested areas. Spatially explicit information is considered an important first step in order to achieve sustainable management, protection and restoration. In this study, we detect the changes in forest cover of Greece for the period 1990 to 2010. Additionally, we test the efficiency of comparing data with overarching differences. Overall, results show a slight - approximately by 2% - decrease in dense forests while sparse forests and shrublands increase - approximately by 7% - in the same period.

K E Y W O R D S (in alphabetical order): *Change detection; CORINE; forests and semi-natural areas; Greece; moving window filter; sustainable management*

1 Introduction

Forests provide a wide range of ecosystem services that can range from an ecological, socio-economic and aesthetic point of view. In brief, forest ecosystems sustain all levels of biodiversity serving as habitat for terrestrial animal and plant species (Costanza et al. 1997), while at the same time maintain soil quality by sediment retention, accumulation of organic material and nutrient cycle (Schoenholtz et al. 2000). Additionally, forest ecosystems influence climate through carbon sequestration (Bonan 2008; Canadell and Raupach 2008) and surface albedo regulation (Sagan et al. 1979). They also directly affect the hydrologic cycling through

evapotranspiration, infiltration and surface runoff (Bosch and Hewlett 1982). Besides these ecosystem services, forests have been perpetually exploited by humans as they constitute a vital source of food, materials and energy supply (Vos and Meekes 1999).

Nevertheless, the substantial increase of human domination resulted in substantial changes of the Earth's land cover, altering the continuity and structure of the natural reserves and degrading environmental conditions (Vitousek et al. 1997). These changes, which are amplified by economic driven mismanagement, pose serious threats to the Earth's capacity for sustainability (Foley et al. 2005). This complex interaction system has attracted the attention of the scientific community during the last decades (Turner et al. 2007). Numerous research projects, organizations, conservation initiatives, legislative interventions and conventions have focused on measures to reduce the negative and irreversible environmental impacts and to confront further deterioration of the land (Turner et al. 1994).

Earth observation through satellite remote sensing has proven to be an effective way to provide accurate and timely information on the distribution and characteristics of forests. In addition, change detection (Coppin et al. 2004) of forest cover can act as a reliable and consistent pool of evidence in order to reveal underlying and proximate causal factor synergies (Geist and Lambin 2002). Recent technological and methodological advancements allowed several geospatial data sets representing Earth's forest cover (or land cover in general) and/or its associated changes, to be produced. The majority of them consists of case studies at a local scale, mostly focusing on the determination of local processes that are often case specific and may not be identifiable at broader scales (Verburg et al. 2004). An integrated analysis of the phenomenon requires a multi-scale (from local to national or even regional to global) assessment. A number of high resolution global datasets exist today (e.g. Hansen et al. 2013; Kim et al. 2014; Potapov et al. 2008), at various temporal scales of analysis. In Europe, the most frequently used land cover (LC) database is the Coordinate Information on the Environment (CORINE), a pan-European LC map for the years 1990, 2000 and 2006, provided by the European Environmental Agency (EEA). Although these research efforts are important to numerous applications at coarser scales, there still exist limitations that need to be addressed (Giri et al. 2013). Regarding forest land cover mapping, the major source of disagreement is the inconsistency and the incomparability between the datasets due to differences in the definition of forests (Hansen et al. 2013).

Nowadays, research on LC has turned into a frequently discussed topic for environmental and social scientists, a fact that increased the construction and distribution of spatial digital data. However, most studies focus on the local or the regional scale and thus, producing case specific datasets. On the other hand, the pan-European's CORINE LC latest update for Greece

was for the year 2000. Given the importance of such a complex phenomenon to be addressed at various scales, we conducted a national scale change detection study of forested and semi-natural areas for Greece. We employed existing available datasets of land cover for the year 1990; 2000 and 2010. The main objectives were: a) to map and quantify the changes occurred in the forests and semi-natural areas of Greece between 1990-2010 and b) to test the effectiveness of inter-comparison between different resolution and minimum mapping unit datasets (CORINE and Landsat derived).

2 Methodology

2.1 Study area

Greece, a Mediterranean Balkan country occupies an area of approximately 132,000 km^2 with a coastline stretching for 15,000 km. Geomorphologically, the Greek territory is complex and heterogeneous, consisting of about 40% mountainous or hilly landscape (land that exceeds 500m in altitude). Extensive agricultural plains are primarily located in Thessaly, Central Macedonia and the Thrace regions. The climate is typical Mediterranean, with hot and dry summers and relatively mild and wet winters. Dominant vegetation types are broadleaved and coniferous forests, sclerophyllous maquis and garrigue (Arianoutsou et al. 1997).

The inhabitants of Greece have a long history of land-based economic activities and to this day forests still constitute a source of income for the rural residents (Papanastasis et al. 2009). The majority of the Greek forests are public and administered by the Hellenic Forest Service, while a large part is owned by Municipalities, charitable foundations and monasteries. Finally, a total area of approximately 200,000 ha is private land and while its land use is determined through legislation frameworks a number of unresolved issues still to be addressed (Vogiatzis 2008). Although formulated regional and national policies regarding sustainability and protection of the natural reserves have been promoted over the last decades (Vokou et al. 2014), forested ecosystems have notably been degraded and fragmented in several areas (Gounaridis et al 2014; Minetos and Polyzos 2010). Arbitrary land tenure arrangements, market induced mismanagement or passive management, lack of public awareness (Minetos and Polyzos 2010) as well as an increasing number of devastating wildland fires (Koutsias et al. 2013) have been identified as the main direct and underlying causes of natural reserves degradation.

2.2. Data and processing

We employed the CORINE land cover datasets for the years 1990 and 2000 produced by the European Environment Agency. The datasets are freely available under the creative commons licensing regime, with a nomenclature that comprises 44 LC classes, organized

hierarchically in 3 levels of detail. The first level indicates the major categories of LC e.g. forests and semi-natural areas. The second level indicates more specific types of LC e.g. forests, while the third level narrows down to more specific characterizations e.g. coniferous forest. The minimum mapping unit is 25 ha (Bossard et al. 2000).

For the year 2010, we used a newly produced dataset of LC for Greece (Gounaridis et al. 2015). Primary data for this dataset were the 2010 Landsat GLS imagery (Gutman et al. 2013), spanning paths: 180 to 186 and rows: 31 to 36. The LC information was derived by implementing the random forests classification algorithm (Breiman 2001). The algorithm was trained semi-automatically, extracting information from the CORINE 2000 LC polygon centroids. The result underwent a series of post processing techniques including the single pixels elimination using the mode of their neighborhood pixels, defined by a 3x3 window. The nomenclature adopted was identical to the CORINE land cover at level 2.

The 2010 dataset, derived from Landsat imagery, was resampled to 100m using the nearest neighborhood method, to allow for comparison with the other two datasets. To deal with the difference in the minimum mapping unit, we re-applied a 5x5 moving window targeting isolated patches of less than 25 ha, using the mode of their neighbors. Next, the datasets were reclassified into four categories focusing on forests and semi-natural areas in order to better distinguish them from the other classes. The final four categories were: forests; shrub and/or herbaceous vegetation associations; open spaces with little or no vegetation; all other types (see Figure 1).

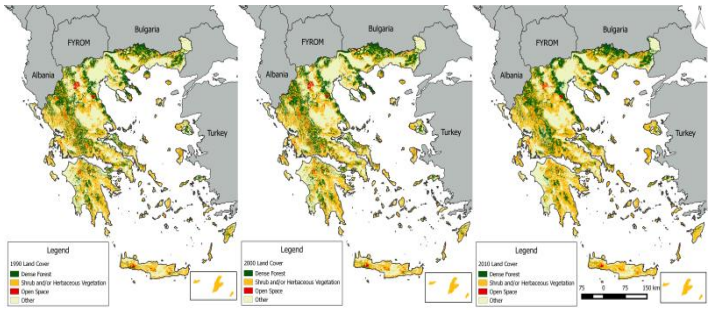

Figure 1: *The final (after pre processing and reclassification) three land cover datasets used for the change detection*

The final stage was the accuracy assessment of the LC classes regarding forests and semi-natural areas. A total of 37,000 randomly distributed points -independent from the original dataset- were photo-interpreted utilizing very high resolution satellite imagery provided by OpenLayers plugin in QGIS (Quantum GIS Development Team, 2013). Visual interpretation analysis is a complex and demanding task, completely based on the interpreter's personal judgment. To efficiently estimate LC, a general assessment of the surroundings is necessary to be taken into consideration. Thus a buffer of 50m diameter was applied to every point. The length of 50m was chosen in order to achieve a compatible minimum mapping unit with the CORINE data to avoid discrepancies during the change detection stage. The objective to define

LC for every single location, considering the wider surroundings, increased the complexity. For such a complex and long duration process, the user agreement, in other words a predefined common sense of the team members, was crucial. Therefore, several exploratory interpretations were conducted. The results of the team members for different parts where switched and the matching entries rate was computed. This procedure continued until an acceptable rate (90%) was reached. Only the points that were commonly assigned by the members were kept. The photo-interpretation performed regarding the current LC taking place in every randomly distributed point's location. Each of the buffer polygons attribute, was labeled a value according to the interpreter's opinion, indicating a land cover class at the CORINE's level 1. Subsequently, we focused on quantifying cover changes of the forests and the semi- natural areas and mapping their spatial distribution. Firstly, the statistics of percent cover of each of the four classes were calculated. Secondly, post-classification (PC) comparison in the form of cross-classification (Lu et al. 2004) was employed, because of its pixel-by-pixel nature and more specifically the 'from-to' change class information provision.

3 Results

From the initial 37,000 points, 20,552 were labeled as forests and semi-natural areas and were chosen to be compared against the 2010 reclassified dataset, resulting in a total accuracy of 92%. The percentages of LC changes that occurred between the years 1990 and 2010 are summarized in Figure 2. A decrease in forested areas (dense forests) is observed (approximately a 2% reduction of the original coverage) between 1990 and 2010. Comparatively, the area of sparse forests and shrubs increased approximately 7% at the same period, while open spaces appear slightly reduced at about 0.4% from their original area. In addition, a small percentage of 1% of sparse forests/shrubs appears to have been converted to dense forests.

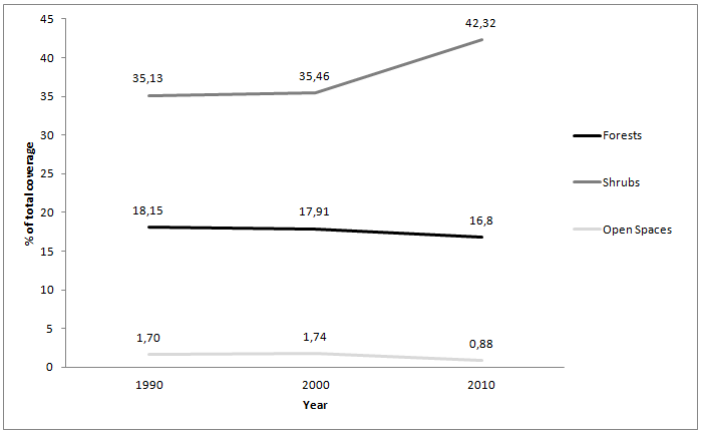

Figure 2: *Percentages of total land occupied by each of the forests and semi-natural areas land cover classes for the three datasets.*

The spatial patterns of changes in LC are illustrated in Figure 3 with a categorization of changes into four classes. The first two categories present the two different forest types that remained unchanged (dense and sparse/shrubs including the slight gain), followed by the changes (loses) of any type of forest to some other artificial LC type. The fourth

category is that of the remaining LC types, aggregated into one category for easier visualization. The results presented focus on the changes that occurred to forests including the percentage lost and the percentage unchanged.

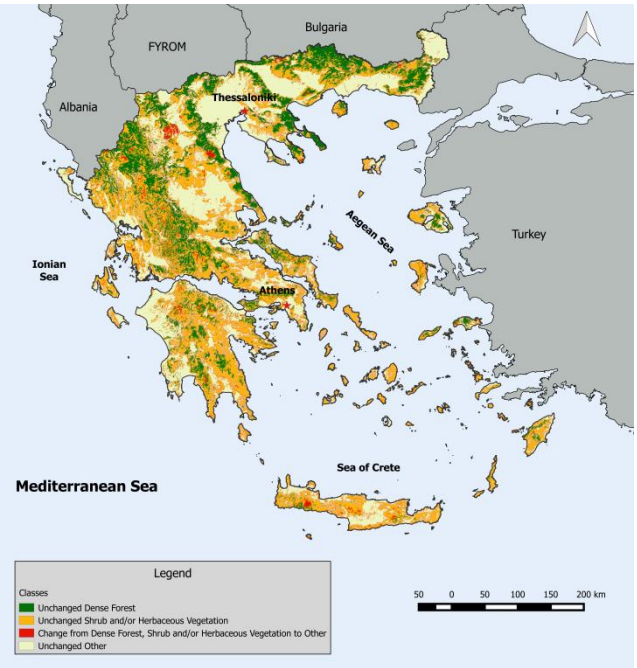

Figure 3: *The spatial patterns of changes in forests and semi-natural areas land cover as revealed by the cross classification methodology*

4 Discussion

The changes in forest cover which are the main focus of this study can be explained by a series of facts. Firstly, Greece has been suffering from extensive forest fires for many years, leading to a significant loss of forested areas (Koutsias et al. 2013). This also leads to a partial explanation regarding the increase appearing in sparse forests and shrubs as it can be seen in Figure 2. Mediterranean ecosystems have very effective mechanisms of coping with fire if left undisturbed after a fire incident (Arianoutsou 1999; Calvo et al. 2002; Le Houerou 1974). Thus, post-fire regeneration (natural or artificial), leads to younger and sparser forests. The increase of shrublands can also be attributed to rural land abandonment (Antrop 2004; MacDonald et al. 2000). During the last decades in Greece, triggered by socio-economic changes and gradual urbanization, remote rural areas have been abandoned and, in many cases, they are gradually transformed into shrubland and or sparse forests (Kasimis et al. 2003; Zomeni et al. 2008)

An issue with this study that should be discussed is that some of the observed changes seem to appear due to the difference in resolution between the datasets used. Both CORINE 1990 and 2000 datasets were acquired at 100m resolution (originally based on the digitization of remote sensing imagery) while the newly developed 2010 dataset was created at 30m resolution through a machine learning classification process (Gounaridis et al. 2015). Despite our efforts to make datasets as comparable as possible (resampling to 100 m and moving window filter for areas <25 ha), differences were not entirely eliminated, thus affecting the accuracy of the results. The majority of the erroneously classified as change pixels can be traced close to the borders (edges) of different land cover patches and it can lead to inaccuracies in LC change detection. The reason for such a result can be traced to the different way edges are represented in the datasets employed for the comparison. This study demonstrates that change detection between

datasets with different resolution and minimum mapping unit should be conducted with caution. Additionally, it is clear that accurate finer resolution datasets are important in LC change detection, a fact that raises challenges for future research.

5 Conclusions

In this study we focused on changes that occurred in forest and semi-natural areas cover during the period between 1990 and 2010 in Greece. The main change observed is the reduction of forest cover by approximately 2% and its substitution by other forms of LC. Sparse forests and shrubs showed a 7% increase in the past 20 years, open spaces were reduced by 4% and finally 1% of sparse forests has changed category to that of dense forests. A series of matters regarding the protection and sustainability of forests arise along with issues regarding land abandonment and the expansion of urban areas lacking proper planning. The issue of forest fires and its implications to the state of forests in Greece is well documented and the resulting loss of forest cover is evident in various areas of the country.

In the context of planning a sustainable forest policy, and at the same time assessing the effectiveness of past activities, spatio-temporal information of land cover and its associated changes, is essential, making it obvious that spatial data construction should be prioritized. Accurate high resolution LC datasets are a key priority for further research, environmental monitoring and land use planning. Additionally, appropriate attention should be given to the compatibility and interoperability between the produced and existing datasets. Dataset construction initiatives require the adoption of new, robust and low cost methodologies.

Acknowledgements: The authors wish to thank the two reviewers and Iosif Botetzagias (on behalf of the Editors of AEJES), for their constructive comments on earlier drafts of this manuscript. Bika Konstantina, Kontou Danai, Moustos Petros and Riga Maria, were under summer internship placement at SAGISRS lab

References

Antrop M. (2004), *Landscape change and the urbanization process in Europe*, Landscape and Urban Planning, 67: 9–26. DOI: 10.1016/S0169-2046(03)00026-4

Arianoutsou, M. 1999. *Effects of fire on vegetation demography.* In: Proceedings of the International Symposium “Forest Fires: Needs and Innovations”, Athens, 18-19 November. DELFI Concerted Action, CINAR-EC, DGXII: 265-273. Available at http://www.uaeco.edu.gr/files/PDF/P_D17.pdf

Arianoutsou M., Delipetrou P., Dimopoulos P., Economidou E., Karagiannakidou V., Kostantinidis P., Panagiotides P., Panitsa M. and Tsiourlis M. (1997), *Habitat Types Present in Greece.* In: (Eds. Dafis, et al.) The Greek “Habitat” Project NATURA 2000: An overview. The Goulandris Natural History Museum–Greek Biotope/Wetland Centre, Athens, Greece, 402-434.

Bonan G.B. (2008), *Forests and Climate Change: Forcings, Feedbacks, and the Climate Benefits of Forests*, Science, 320: 1444-1449. DOI: 10.1126/science.1155121

Bosch J.M. and Hewlett J.D. (1982), *A review of catchment studies to determine the effect of vegetative changes on water yield and evapotranspiration*, Journal of Hydrology, 55: 3–23. DOI: 0022-1694/82/0000--0000/$ 02.75

Bossard M., Feranec J. and Otahel J. (2000), *CORINE land cover technical guide –Addendum 2000*, Technical report, 40. European Environment Agency. Copenhagen. Available at: http://www.eea.europa.eu/publications/tech40add

Breiman, L. (2001). *Random forests*. Machine Learning, 40:5–32.

Calvo L., Tarrega R. and De Luis E. (2002), *The dynamics of mediterranean shrubs over 12 years following perturbations*, Plant Ecology, 160: 25-42. DOI: 10.1023/A:1015882812563

Canadell J.G. and Raupach M.R. (2008), *Managing Forests for Climate Change Mitigation*, Science, 320: 1456-1457. DOI: 10.1126/science.1155458

Coppin P., Jonckheere I., Nackaerts K., and Muys B. (2004), *Digital change detection methods in ecosystem monitoring: a review*. International Journal of Remote Sensing, 25:1565–1596.
DOI: 10.1080/0143116031000101675

Costanza, R., dArge, R., deGroot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Suttonkk, P., and Van den Belt, M. (1997), *The value of the world's ecosystem services and natural capital*, Nature, 387: 253–260. DOI: 10.1038/387253a0

Foley J.A., DeFries R., Asner G.P., Barford C., Bonan G., Carpenter S.R., Chapin F.S., Coe M.T., Daily G.C., Gibbs H.K., Helkowski J.H., Holloway T., Howard E.A., Kucharik C.J., Monfreda C., Patz J.A., Prentice C., Ramankutty N. and Snyder P.K. (2005), *Global Consequences of Land Use*, Science, 309: 570–574. DOI: 10.1126/science.1111772

Geist H.J. and Lambin E.F. (2002), *Proximate Causes and Underlying Driving Forces of Tropical Deforestation*, BioScience, 52(2): 143-150. DOI:10.1641/0006-3568(2002)052[0143: PCAUDF] 2.0. CO;2

Giri C., Pengra B., Long J. and Loveland T.R. (2013), *Next generation of global land cover characterization, mapping, and monitoring*, International Journal of Applied Earth Observation and Geoinformation, 25: 30–37. DOI: 10.1016/j.jag.2013.03.005

Gounaridis D, Zaimes G.N. and Koukoulas S. (2014). *Quantifying spatio-temporal patterns of forest fragmentation in Hymettus Mountain, Greece*, Computers, Environment and Urban Systems, 46: 35–44. DOI: 10.1016/j. compenvurbsys.2014.04.003

Gounaridis D., Apostolou A. and Koukoulas S. (2015), *Land Cover of Greece, 2010: a Semi Automated Classification Using Random Forests*, Journal of Maps, DOI: 10.1080/17445647.2015.1123656

Gutman G., Huang C., Chander G., Noojipady P. and Masek J.G. (2013), *Assessment of the NASA–USGS Global Land Survey (GLS) datasets*, Remote Sensing of Environment, 134: 249–265. DOI: 10.1016/j.rse.2013.02.026

Hansen M.C., Potapov P.V., Moore R., Hancher M., Turubanova S.A., Tyukavina A., Thau D., Stehman S.V., Goetz S.J., Loveland T.R., Kommareddy A., Egorov A., Chini L., Justice C.O. and Townshend J.R.G. (2013). *High-resolution global maps of 21st-century forest cover change*, Science, 342(6160): 850–853. DOI: 10.1126/science.1244693

Kasimis C., Papadopoulos AG. and Zacopoulou E. (2003). *Migrants in Rural Greece.* Sociologia Ruralis, 43: 167–184. DOI: 10.1111/1467-9523.00237

Kim, D.H., Sexton, J.O., Noojipady P., Huang C., Anand A., Channan S., Feng M., Townshend J.R. (2014), *Global, Landsat-based forest-cover change from 1990 to 2000*, Remote Sensing of Environment, 155: 178–193. DOI: 10.1016/ j.rse.2014.08.017

Koutsias N., Xanthopoulos G., Founda D., Xystrakis F., Nioti F., Pleniou M., Mallinis G.

and Arianoutsou M. (2013), *On the relationships between forest fires and weather conditions in Greece from long-term national observations (1894–2010)*, International Journal of Wildland Fire, 22: 493–507. DOI: 10.1071/WF12003

Le Houerou H.N. (1974), Fire and vegetation in the Mediterranean basin. In: Proceedings of the 13th Annual Tall Timbers Fire Ecology Conference, Rome, 237-277.

Lu D., Mausel P., Brondizio E. and Moran E. (2004), *Change detection techniques*, International Journal of Remote Sensing, 25(12): 2365–2407.
DOI:10.1080/0143116031000139863

MacDonald D., Crabtree J.R., Wiesinger G., Dax T., Stamou N., Fleury P., Gutierrez Lazpita J. and Gibon A. (2000), *Agricultural abandonment in mountain areas of Europe: Environmental consequences and policy response*, Journal of Environmental Management, 59: 47–69. DOI:10.1006/jema.1999.0335

Minetos D. and Polyzos S. (2010), *Deforestation processes in Greece: A spatial analysis by using an ordinal regression model*, Forest Policy and Economics, 12: 457–472. DOI:10.1016/j.forpol.2010.02.0

Papanastasis P.V., Mantzanas K., Dini-Papanastasi O. and Ispikoudis I. (2009), *Traditional Agroforestry Systems and Their Evolution in Greece*. In A. Rigueiro-Rodriguez, J. McAdam, & M.R. Mosquera-Losada (Eds.), Agroforestry in Europe Current Status and Future Prospects (pp. 89-109). Springer.

Potapov, P., Yaroshenko, A., Turubanova, S., Dubinin, M., Laestadius, L., Thies, C., Aksenov D., Egorov A., Yesipova Y., Glushkov I., Karpachevskiy M., Kostikova A., Manisha A., Tsybikova E., Zhuravleva I. (2008), *Mapping the world's intact forest landscapes by remote sensing*. Ecology and Society, 13(2): ART51. Available at: http://www.ecologyandsociety.org/vol13/iss2/art51/

Quantum GIS Development Team (2013). Quantum GIS Geographic Information System. Open Source Geospatial Foundation Project. http://qgis.osgeo.org

Sagan C., Toon O.B. and Pollack J. B. (1979), *Anthropogenic albedo changes and the Earth's climate*, Science, 206: 1363–1368. DOI:10.1126/science.206.4425.1363

Schoenholtz S.H., Van Miegroet H. and Burger J.A. (2000), *A review of chemical and physical properties as indicators of forest soil quality: challenges and opportunities.* Forest Ecology and Management, 138: 335-356. PII: S0378-1127(00)00423-0

Turner B.L., Meyer W.B. and Skole D.L. (1994), *Global Land-Use/Land-Cover Change: Towards an Integrated Study*, Ambio, 23: 91-95.

Turner II B.L., Lambin E.F. and Reenberg A. (2007), *The emergence of land change science for global environmental change and sustainability*, Proceedings of National Academy of Science, 104(52): 20666–20671. DOI: 10.1073pnas.0704119104

Verburg P.H., Schot P.P., Dijst M.J. and Veldkamp A. (2004), *Land use change modelling: current practice and research priorities*, GeoJournal, 61: 309–324. DOI:10.1007/s10708-004-4946-y

Vitousek P.M., Mooney H.A., Lubchenco J. and Melillo J.M. (1997), *Human domination of Earth's ecosystems*. Science, 277: 494–499. DOI:10.1126/science.277.5325.494

Vogiatzis M. (2008), *Cadastral Mapping of Forestlands in Greece: Current and Future Challenges*, Photogrammetric Engineering & Remote Sensing, 74(1): 39–46. DOI: 0099-1112/08/7401–0039/$3.00/0

Vokou D., Dimitrakopoulos P.G., Jones N., Damialis A., Monokrousos N., Pantis J.D., Mazaris A.D. and The Natura-2000 Committee (2010–2013) members (2014), *Ten years of co-management in Greek protected areas: an evaluation*, Biodiversity and Conservation, 23: 2833–2855. DOI: 10.1007/s10531-014-0751-1

Vos W. and Meekes H. (1999), *Trends in European cultural landscape development: perspectives for a sustainable future*, Landscape and Urban Planning, 46: 3-14. PII: S0169-2046(99)00043-2

Zomeni M., Tzanopoulos J. and Pantis JD. (2008), *Historical analysis of landscape change using remote sensing techniques: an explanatory tool for agricultural transformation in Greek rural areas*. Landscape and Urban Planning, 86: 38–46. DOI: 10.1016/j.landurbplan. 2007.12.006

AEJES (2016) pp. 11-23

The interdisciplinary Development of the Term "Soundscape"; Tracing its Ecological Roots

Yiannis G. Matsinos, Aggelos Tsaligopoulos & Chris Economou

A U T H O R S I N F O

Yiannis G. Matsinos* is an Associate Professor in the Department of the Environment, University of the Aegean (DoE, UoA) and is the Director of the Acoustic Ecology Laboratory

Aggelos Tsaligopoulos is a PhD candidate in the Acoustic Ecology Laboratory, DoE, UoA, Greece

Chris Economou holds a PhD and is a head researcher in the Acoustic Ecology Laboratory, Department of the Environment, University of the Aegean (DoE, UoA), Greece

**email*: matsinos@aegean.gr

A B S T R A C T

Even though the term "*soundscape*" is strictly ecological, it has been incorporated in various interdisciplinary studies. The definitions attributed to this term to date, in chronological order, reveal its ecological roots. Nevertheless, the ecological background of soundscapes did not pose as a barrier towards its expansion, but was rather beneficiary towards environmental sciences and other disciplines. These incorporations are the reason for the theoretical broadening of the term. This specific review highlights the use of an ecological term in non-ecological disciplines. Furthermore, the mapping of this extension over the years as well as the identifying any trends in the term's use per discipline, haven't been researched to date. In order to answer these questions, we initially assessed all publications appearing between 1969 and 2011 that incorporated the term "soundscape" in their title (about 3,200 references). Multiple and non-scientific entries were excluded from the research by filtering the results. The final dataset (979 entries) was classified regarding year of publication and scientific sub-discipline. Our results indicate "outbursts" regarding publication number in soundscape literature that could be attributed amongst other reasons, to several legislative developments concerning the assessment and management of environmental noise.

K E Y W O R D S (in alphabetical order): *Acoustic Ecology, Soundscape, Soundscape Ecology, Soundwalk*
Highlights

1. Introduction

Since R. Murray Schafer in the early 70's introduced the term "soundscape", the interdisciplinary development of its use seems to follow a significantly increasing trend. Soundscape studies are a major area of research on the scientific field of acoustic ecology. The World Soundscape Project (WSP) that was established by R. Murray Schafer at Simon Fraser University in the late 1960s-early 1970s, produced several publications including "*The Tuning of the World*" (Schafer, 1977) and Barry Truax's reference work for acoustic and soundscape terminology "*Handbook for Acoustic Ecology*" (Truax, 1978). The term "soundscape" in Truax's handbook is defined as the "*environment of sound (or sonic environment)*

with emphasis on the way it is perceived and understood by the individual, or by a society". This definition was adopted by the technical committee on acoustics (TC 43) of the International Organization of Standardization (ISO) Working Group 54, regarding the perceptual assessment of soundscape quality ('Committee ISO/TC 043 "Acoustics"', 2008). Furthermore, the field of ecoacoustics, which studies biological and non-biological sounds along a broad range of spatio-temporal scales, includes soundscape ecology and examines the ecological processes of a soundscape under several environmental pressures (Sueur & Farina, 2015).

"*Only silence lay over the fields and woods and marsh*'', were the words of Rachel Carson in her book 'Silent spring' (Carson, 1962). The alteration of a soundscape which was described in Carson's memories was the trigger for the 'awakening' to major ecological issues. The loss of biophony over the fields, woods and marshes is equivalent to the anthropophony increase in the cities, which poses a warning regarding the acoustic quality of urban soundscapes and the well-being of its residents. Cities have changed dramatically over the years, shaping the acoustic and visual domain in both positive and negative ways. Several sounds that are associated with specific urban practices (e.g. transportation) might have changed over the years due to technological advancements. Nevertheless, cities have always been noisy places and despite the fact that particular urban sounds and their sources differentiate, the reason of propagation is still the same (Garrioch, 2003). Ecological, social, political, economic and even religious factors, contributed in the shaping of a city's soundscape. Cultural habits for example, originating from the fourteenth century (like the Christian church bell ringing and the Muslim mosque calls) served as influential factors regarding the religious acoustic profile of Europe (Garceau, 2011).

The subjective dimension of acoustic perception has resulted in different attitudes and "feelings" towards soundscapes. The positive or negative reaction on a sound does not depend entirely upon the sound itself but also upon the associated behaviors and experience of the listener, the visual context, the related memories associated with the sound and the emotions which could be either positive or negative (Liu & Kang, 2016). The philosophical dimension of sound perception has troubled thinkers for many decades. The well-known philosophical thought experiment "*If a tree falls in a forest and no one is around to hear it, does it make a sound?*" appeared as a reader's question in the Scientific American magazine (Scientific American, 1884). Furthermore, the same "rhetorical" question reappeared in the book "*Physics*" by Charles Riborg Mann and George Ransom Twiss, in 1910 (Mann & Twiss, 1905). This question was addressed by giving a technical answer regarding acoustics, stating that undoubtedly there will be vibrations yet no sound -since there will be no one around to accept and interpret the

aforementioned vibrations. It is now known that the generation, propagation and perception of sound is strongly connected with mechanical vibrations and oscillations that result to sound waves (Kuttruff, 2007). Nevertheless, the answer to the same question would be different if the issue of annoyance was incorporated. If there is no witness to confirm "the tree's fall", its fall does make a sound but it surely does not make a noise. The presence of any form of life, human or animal, so that annoyance can take place, is essential for the subjective transition from sound to noise. Sound wave propagation is an objective matter due to the fact that nature does not require a spectator in order to function. However, noise is subjective, entirely depending on the receiver's tolerance and preference.

1.2. Soundscape Definitions

Several versions of the term "soundscape" were used over the years in scientific literature. Almo Farina, in his book "*Soundscape Ecology: Principles, Patterns Methods and Applications*" (Farina, 2014) defines the soundscape as the entire sonic energy produced by a landscape. The foreground and background sounds, in relation to the sound source and the position of the listener, outline the association between the soundscape and the landscape. The unpredictability and temporal variability of foreground sounds that create an immediate reaction to the listener are less connected to the landscape configuration. Therefore, the background sounds which refer to the low-level sounds that result from the blend of several individual sound sources are highly associated with the landscape. The spatio-temporal overlap of geophonic, biophonic, and anthrophonic foreground sounds creates the "sonotopes" that when further shaped by vocal organisms create the "soundtopes" (Farina, 2014). Soundscape ecology, as a promising field of ecological research, emphasizes the ecological characteristics of sounds and their spatiotemporal patterns as they emerge from landscapes (Pijanowski et al., 2011b). Moreover, it is described as the study of sound in the landscape and its effects on organisms and how different acoustic sources interact at spatial and temporal scales (Pijanowski et al., 2011a).

The link between landscape and soundscape ecology in natural acoustic environments highlights the connection amongst the "soundscape" and the "eco-field". The "eco-field" concept refers to the physical space and the associated abiotic and biotic characters perceived by a species when a functional trait is active (Farina, 2000). The connection with the soundscape concept derives through the biosemiotics approach to avian acoustic communication, which refers to the study of sound patterns structured into syllables, phrases, verses and strophes, along with the combination of these elements (Farina & Belgrano, 2006).

Transportation noise, industrial noise, recreational noise, noise produced by animals and sounds like rain and the reflection of the wind on various surfaces, are part of the "acoustic field" (Brown & Lam, 1987). The

information of the dynamics of an ecosystem in a specific time and place and the effects of anthrophony and geophony to the ecosystem as a whole, are described by (Krause, 1987) as the unique "acoustical bio-spectrum". One of the most recent definitions given to "soundscape" is "*the collection of biological, geophysical and anthropogenic sounds that emanate from a landscape and which vary over space and time reflecting important ecosystem processes and human activities*" (Pijanowski et al., 2011a)

Soundscapes represent a group of immaterial resources that are ecologically, culturally and economically valuable (Farina & Pieretti, 2012). Research on the visual qualities of a landscape, demonstrates the strong connections between sense of place and sound. In cultural landscapes, the soundscape is the result of mutual progress between human culture and natural processes (O'Connor, 2008). Sounds are considered essential factors of place making. Hence, cultural soundscapes should be protected and preserved as cultural heritage.

2. Methodology

In order to study the career of the term "soundscape" in the academic literature, all publications appearing between 1969 and 2011 that incorporated the term "soundscape" in their title (about 3.200 references), were assessed through the global literature. The databases used for this research were: a) Google Scholar, b) Web of Science (formerly known as "web of Knowledge") and c) Google Search. Due to the vast amount of data collected, a customized script was used in order to transfer data in an sql database and then to an open-source reference management software ('Zotero') in order to clear multiple and non-scientific entries. The final, cleared, dataset (979 entries) was classified by year of publication and scientific discipline. The subcategories were then grouped into three main categories of: a) Natural Sciences, b) Technology and c) Social Sciences – Arts. The final, main category, results were introduced in the statistical analysis software SPSS v.19, in order to describe trends.

The "soundscape", as a term, has conceptually extended, as it is evident from the fact that it is used by a wide variety of interdisciplinary areas in global literature. For almost 50 years since 1969, where the term "soundscape" was first introduced by R. Murray Schafer (Schafer & Murray, 1969) the scientific areas of: a) social sciences, arts and humanities, b) engineering, computer science and mathematics, c) biology, life sciences and environmental science, incorporated the soundscape terminology. These incorporations are the reason for the theoretical broadening of the term. The tracking of this extension over the years, as well as identifying any trends in the term's use per discipline, haven't been researched to date. Establishing these facts could lead to numerous conclusions regarding development in the field of acoustics. Several examples highlighting concerns which induced

research topics across the various disciplines are listed below, regardless the year of publication.

3. Disciplines of Interest

3.1. Social Sciences, Arts and Humanities

The relationship between individuals in a soundscape context and the positive or negative effects of soundscapes in human societies generated numerous publications in the field of social science. Several sub disciplines of soundscape and acoustic ecology emerged in order to tackle the ever increasing noise related concerns. Psychoacoustics is a major field of research that deals with issues of acoustic perception. It refers to the study of the psychological and physiological responses of human beings and other forms of life to their acoustic surroundings. One of the pioneers in the field of psychoacoustics was the Hungarian biophysicist Georg von Békésy who was awarded the Nobel Prize in Physiology or Medicine in 1961 for his research on the function of the cochlea in the mammalian hearing organ. Apart from his work on the physiological responses on hearing, Georg von Békésy also published various research in the field of psychophysics, including publications dealing with the senses of hearing, balance, vision, touch, taste, and smell (Moore, 2012). Several psychoacoustic semantics (word meanings) like "loudness", "quietness" and "sharpness", are used in order to describe acoustic comfort in soundscapes (Kang, 2010). Furthermore, the relationship between the individual experience and subjectivity with a physical and a socio - cultural perspective is important for the assessment of the perceptual, psychoacoustic and acoustic properties of soundscapes (Hall et al., 2013).

The concerns regarding acoustic perception could be dealt with using several techniques that are able to assess the subjective and personal act of hearing. Qualitative surveys, that most regularly are accompanied by quantitative data (e.g. noise level measurements), are the basis of acoustic perception assessment. Recent surveys regarding soundscape preferences have concluded that natural sounds are not only the most preferable sounds in a landscape but also the most influential soundscape element of acoustic perception (Marry & Defrance, 2013). Furthermore, natural soundscapes that include biotic sounds (e.g. bird songs) could have stress-relief potentials (Ratcliffe et al., 2013). Nevertheless, natural sounds and soundscapes could still cause undesirable emotions if associated by individuals with negative experiences (Ismail, 2014). Research on the positive sounds (i.e. that shape soundscapes positively), is a major issue of the field. Recent studies concluded that individuals perceive positively the water sounds (Axelsson et al., 2014).

A key feature of an acoustically healthy city is the degree of awareness amongst its inhabitants regarding ecological issues. Methodologies such as soundwalks, directly

involve stakeholders by promoting awareness regarding the individual contribution to the quality of the acoustic environment (Jeon & Hong, 2015). According to Hildegard Westerkamp, a soundwalk is any excursion whose main purpose is listening to the environment. The three states of listening, listening in search, listening in readiness and background listening (Truax, 2001); (Jennings & Cain, 2013) could contribute to a better understanding of the personal act of listening at a broader scale. The purpose of this procedure is soundscape evaluation, by using primarily the sense of hearing.

The landscape attributes of a public space, either natural or man-made, influences the acoustic perception of its users (Matsinos et al., 2008). Furthermore, the quality of soundscapes could be improved if the spatial arrangements of different landscape elements are considered in landscape and urban planning (Liu & Kang, 2016). The soundwalking practice has proven to be a valuable tool for soundscape studies and could set the ground for future soundscape remodeling. "Soundwalking" consists of a pre-selected route with several stops representing a variety of soundscapes. A group of stakeholders follows that route in silence, surveying both the soundscape and landscape. The flexibility of its methodology allows novel alterations that could serve different purposes regarding the scope of each research. The soundscape and landscape variety of each soundwalk and the objectives of each research are the main reasons of procedure modifications. A good soundwalk example is the positive soundscape project (Adams et al., 2008; Davies et al., 2013) that highlighted both the negative and positive acoustic aspects of Manchester, UK.

Finally, a major development in social sciences and humanities has been the emergence of sound studies. This relatively new interdisciplinary field assesses the differentiation of aural culture though history and evaluates the way that humans interact with their acoustic environment, in order to "learn" to judge a society by its sounds (Attali, 1985); (Thompson, 2004); (Pinch & Bijsterveld, 2011). Noise studies isolate sound from the way human beings understand it and they treat sound as a signal to be processed rather than as information to be understood (Truax, 1978). Instead sound studies examine the entire continuum of sound, including both the negative and positive qualities of the soundscape (Porteous & Mastin, 1985).

3.2. Engineering, Computer Science and Mathematics

The 2002/49/EC directive (*2002/49/EC Directive on the assessment and management of environmental noise*, n.d., p. 49) has given the necessary guidelines for the assessment and management of environmental noise. The definition given regarding environmental noise in the Environmental Noise Directive (see above) is "the unwanted or harmful outdoor sound created by human activities, including noise emitted by means of transport, road traffic,

rail traffic, air traffic, and from sites of industrial activity". A type of environmental noise is the background or ambient noise, which refers to any sound other than the sound under consideration. Even though background noise is not limited to anthropogenic sounds, it is widely acknowledged that it refers to a form of noise pollution or interference from a main objective, mainly in the field of acoustic engineering.

Soundscape studies rely on technological advancements to address the needs of noise abatement. A common method for the visualization of changes in a soundscape, caused by human actions, is noise mapping. According to END (Environmental Noise Directive) all EU Member States are required to produce strategic noise maps in their main cities, in order to visualize the propagation of transportation and industrial noise and assess population exposure. Noise modeling processing, in combination with noise cartography software, is used in order to portray noise pollution in urban and rural environments for future decision making. Traffic noise which is a major issue in human wellbeing and the quality of the environment is assessed using cartographic data and traffic flow rates. Noise mapping software similar to the Computer Aided Noise Abatement software ('DataKustik: CadnaA', n.d.) could be used in order to address noise issues in urban soundscapes. Traffic flow data, building height and structure, population density, façade exposure, road classification (Suárez & Barros, 2014) and verification via noise measurements (Fiedler & Zannin, 2015) are all crucial information needed for the noise modeling scenarios.

Complexity and diversity of agglomerations is an obstacle when addressing the common problem of noise assessment. Noise modeling processing could be a challenging task due to urban structure peculiarities (Nega et al., 2013). The road networks that differ in road geometry and driving habits in combination with the urban structure could form street canyons which are one of the largest causes of noise propagation in urban soundscapes (Janczur et.al. 2006; (Abhijith & Gokhale, 2015; Janczur et al., 2006). Noise abatement policies have adopted various noise mapping techniques in order to address issues in noisy soundscapes and upgrade the degraded acoustic environment. The technological advancements could allow noise modeling and mapping in larger scales for various purposes and even be the stepping stone for future soundscape creation (Vogiatzis, 2012; Vogiatzis & Remy, 2014).

3.3. Biology, Life Sciences and Environmental Science

Under specific conditions, high intensity sounds could be perceived as noise. It is generally understood that human beings are not the only species that are affected by noise. The specific environmental pressure, amongst other issues, affects the communicational process of organisms. For example, anthropogenic sounds could create an inhospitable soundscape for several animal species that become more

vulnerable to their predators due to the fact that their attention is distracted (Chan et al., 2010). The mating system of several songbirds and of other vocal species that use auditory signals could be affected by the increase of environmental noise, eroding the strength of sexual selection and possibly their genetic structure (Swaddle & Page, 2007). Previous studies have concluded that communication in noise conditions and the ability to extract information in the presence of background noise could have numerous effects (Brumm & Slabbekoorn, 2005). The difficulty to recognize and interpret sound signals in a noise environment is common in human beings and animals and is also called "the cocktail party" problem (Bee, 2008). Noisy environments could cause shifts in signal amplitude but also in the minimum frequency domain (Slabbekoorn & Peet, 2003); (Nemeth & Brumm, 2009).

Soundscapes play a major role in vocal communication in which many animal species rely on. Especially in urban soundscapes, the increased background or ambient noise that could mask vocal signals (Mendes et al., 2011) and cause frequency adjustments (Hu & Cardoso, 2010) along with the loss of habitat features could be the reason of disappearance of several urban bird species (Slabbekoorn & Ripmeester, 2008).

Habitat-dependent patterns of sound transmission, effects of noise, signal perception, and signal interpretation are the major communicational problems that birds and especially song birds (Beckers et al., 2003) as senders and receivers need to adapt to, in order to "get the message across". Signal degradation between emitters and receivers has been an inspiring subject for evolutionary issues in animal communication.

Anthropogenic noise is not the only "type" of noise that could cause communicational issues. There are many natural sources of noise, including streams, wind and other animals (e.g. insect choruses), providing opportunities for elevated noise levels (Warren et al., 2006).

In comparison to human generated noise, natural noise is handled by organisms in a different way. Anthropophony produces annoyance, chronic stress and hearing loss, while natural noise (e.g. noise from a waterfall) can be either physically avoided by an organism, or this organism could be adapted to filter it out. The above statement could be attributed to both human beings and animals. Previous studies have concluded that natural or ecological sounds induce positive emotions to human beings (Ferri et al., 2015). Nevertheless, human response and emotion to natural sounds or noise could possibly be irrelevant to the physical effects of noise that creates disturbances in communicational processes, masking the signal's frequencies.

4. Results and Discussion

The soundscape concept in direct correlation to ecology is used with much more interest from

all other disciplines than natural sciences (Figure 1). Even though the "soundscape" term could be credited to natural sciences the lack of interest in that field could lead to various conclusions. The rapid technological advancements in areas like signal processing, could explain the upward trend regarding the related publications in computer sciences since the year 2000. The upward trend regarding social sciences and arts observed almost since the beginning of the records, could be attributed to the "creator's" status as a music composer and social scientist. Furthermore, the personal act of hearing and the individual interpretation of a "soundscape" could have steered towards an increase of interest as far as the social sciences are concerned.

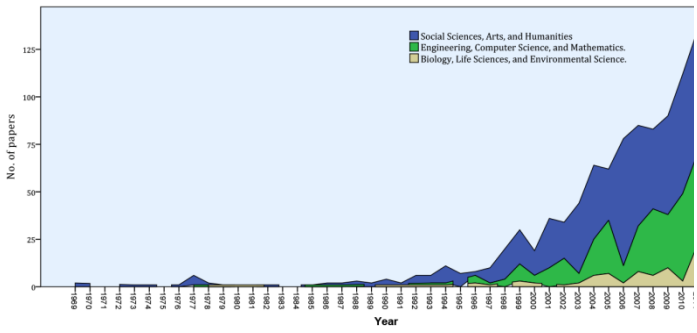

Figure 1*: N_o of publications per disciplinary category between Yrs 1969-2011, regarding the use of the term "soundscape" in global literature*

Finally, a sudden upwards trend is clearly observed for all disciplines after year 2006. A reason for this event could be the direct connection of acoustic and soundscape ecology to issues concerning environmental noise. In the 2002/49 directive (article 10.1), the need was stressed for member states to submit (by January 2004) a report on existing community measures relating to noise issues. This act by the member states was to be completed by the implementation of legislative proposals regarding the same issue, no later than the year 2006**.**

Furthermore, just by observing the relative literature of each year's scientific publications it is obvious that interests shifted towards soundscape – based issues mostly in urban communities. Researches on the quality of soundscapes (De Coensel & Botteldooren, 2006; Guastavino, 2006; Nilsson & Berglund, 2006) have concluded upon the ideal acoustic conditions on rural and urban areas. Noise annoyance and sleep disturbance issues (Botteldooren et al., 2006), noise mapping techniques (Klaeboe et al., 2005) for urban areas, socio-acoustic surveys regarding traffic noise in order to assess quiet soundscapes (Öhrström et al., 2006) and soundscape planning for therapeutic activities (Yamada, 2006) were some of the interests regarding publications in 2006.

The direct association of the term "soundscape" with the ecologically-derived concept of landscape is indubitable. Furthermore, acoustic and soundscape ecology use terms similar to the acoustic niche hypothesis (Krause, 1987) that are borrowed from, and later on adjusted by, the conceptual framework of ecology. Nevertheless, the observed declining share of references to this

ecological term in the environmental sciences' literature vis-à-vis other disciplines should not only be interpreted as a "lack of interest" amongst ecologists. Acoustic and Soundscape ecology should be considered as inherently ecological academic disciplines that contribute equally in the vast of field of ecology.

References

2002/49/EC Directive on the assessment and management of environmental noise. (n.d.). Retrieved from http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=URISERV:l21180

Abhijith, K. V., & Gokhale, S. (2015). *Passive control potentials of trees and on-street parked cars in reduction of air pollution exposure in urban street canyons*. Environmental Pollution, 204:99–108. http://doi.org/10.1016/j.envpol.2015.04.013

Adams, M. D., Bruce, N. S., Davies, W. J., Cain, R., Jennings, P., Carlyle, A., … Plack, C. (2008). Soundwalking as a methodology for understanding soundscapes. In Proc Inst Acoust, 30(2):552–558. Reading, U.K. Retrieved from http://usir.salford.ac.uk/2461/

Attali, J. (1985). *Noise: The Political Economy of Music*. Manchester University Press.

Axelsson, Ö., Nilsson, M. E., Hellström, B., & Lundén, P. (2014). *A field experiment on the impact of sounds from a jet-and-basin fountain on soundscape quality in an urban park*. Landscape and Urban Planning, 123:49–60. http://doi.org/10.1016/j.landurbplan.2013.12.005

Beckers, G. J. L., Suthers, R. A., & Cate, C. ten. (2003). *Mechanisms of frequency and amplitude modulation in ring dove song*. Journal of Experimental Biology, 206(11):1833–1843. http://doi.org/10.1242/jeb.00364

Bee, M. A. (2008). *Finding a mate at a cocktail party: spatial release from masking improves acoustic mate recognition in grey treefrogs*. Animal Behaviour, 75(5):1781–1791. http://doi.org/10.1016/j.anbehav.2007.10.032

Botteldooren, D., De Coensel, B., & De Muer, T. (2006). *The temporal structure of urban soundscapes*. Journal of Sound and Vibration, 292(1–2):105–123. http://doi.org/10.1016/j.jsv.2005.07.026

Brown, A. L., & Lam, K. C. (1987). *Urban noise surveys*. Applied Acoustics, 20(1):23–39. http://doi.org/10.1016/0003-682X(87)90081-8

Brumm, H., & Slabbekoorn, H. (2005). Acoustic Communication in Noise. In Advances in the Study of Behavior, 35:151–209. Elsevier. http://doi:10.1016/s0065-3454(05)35004-2

Carson, R. (1962). *Silent Spring*. Houghton Mifflin Harcourt.

Chan, A. A. Y.-H., Giraldo-Perez, P., Smith, S., & Blumstein, D. T. (2010). *Anthropogenic noise affects risk assessment and attention: the distracted prey hypothesis*. Biology Letters, 6(4):458–461. http://doi.org/10.1098/rsbl.2009.1081

Committee ISO/TC 043 'Acoustics'. (2008). Retrieved 20 April 2016, from http://isotc.iso.org/livelink/livelink?func=ll&objId=8796219&objAction=browse&viewType=1

DataKustik: CadnaA. Retrieved 20 October 2015, from http://www.datakustik.com/en/products/cadnaa

Davies, W. J., Adams, M. D., Bruce, N. S., Cain, R., Carlyle, A., Cusack, P., … Poxon, J. (2013). *Perception of soundscapes: An interdisciplinary approach*. Applied Acoustics, 74(2):224–231. http://doi.org/10.1016/j.apacoust.2012.05.010

De Coensel, B., & Botteldooren, D. (2006*). The quiet rural soundscape and how to characterize it*. Acta Acustica United with Acustica, 92(6):887–897. http://www.ingentaconnect.com/content/dav/aaua/2006/00000092/00000006/art00006

Farina, A. (2000). *Landscape Ecology in Action*. Dordrecht: Springer Netherlands. Retrieved from http://link.springer.com/10.1007/978-94-011-4082-9

Farina, A. (2014). *Soundscape Ecology Principles, Patterns, Methods and Applications*. Spinger.

Farina, A., & Belgrano, A. (2006). *The Eco-field Hypothesis: Toward a Cognitive Landscape*. Landscape Ecology, 21(1):5–17. http://doi.org/10.1007/s10980-005-7755-x

Farina, A., & Pieretti, N. (2012). *The soundscape ecology: A new frontier of landscape research and its application to islands and coastal systems*. Journal of Marine and Island Cultures,1(1):21–26. http://doi.org/10.1016/j.imic.2012.04.002

Ferri, F., Tajadura-Jiménez, A., Väljamäe, A., Vastano, R., & Costantini, M. (2015). *Emotion-inducing approaching sounds shape the boundaries of multisensory peripersonal space*. Neuropsychologia, 70:468–475. http://doi.org/10.1016/j.neuropsychologia.2015.03.001

Fiedler, P. E. K., & Zannin, P. H. T. (2015). *Evaluation of noise pollution in urban traffic hubs—Noise maps and measurements*. Environmental Impact Assessment Review, 51:1–9. http://doi.org/10.1016/j.eiar.2014.09.014

Garceau, M. E. (2011). *'I call the people.' Church bells in fourteenth-century Catalunya*. Journal of Medieval History, 37(2):197–214. http://doi.org/10.1016/j.jmedhist.2011.02.002

Garrioch, D. (2003). *Sounds of the city: the soundscape of early modern European towns*. Urban History, 30(1):5–25. http://doi.org/10.1017/S0963926803001019

Guastavino, C. (2006). *The ideal urban soundscape: Investigating the sound quality of French cities*. Acta Acustica United with Acustica,92(6):945–951. http://www.ingentaconnect.com/content/dav/aaua/2006/00000092/00000006/art00013

Hall, D. A., Irwin, A., Edmondson-Jones, M., Phillips, S., & Poxon, J. E. W. (2013). *An exploratory evaluation of perceptual, psychoacoustic and acoustical properties of urban soundscapes*. Applied Acoustics, 74(2):248–254. http://doi.org/10.1016/j.apacoust.2011.03.006

Hu, Y., & Cardoso, G. C. (2010). *Which birds adjust the frequency of vocalizations in urban noise?* Animal Behaviour, 79(4):863–867. http://doi.org/10.1016/j.anbehav.2009.12.036

Ismail, M. R. (2014). *Sound preferences of the dense urban environment: Soundscape of Cairo*. Frontiers of Architectural Research, 3(1):55–68. http://doi.org/10.1016/j.foar.2013.10.002

Janczur, R., Walerian, E., & Czechowicz, M. (2006). *Influence of vehicle noise emission directivity on sound level distribution in a canyon street.* Part I: Simulation program test. Applied Acoustics, 67(7):643–658. http://doi.org/10.1016/j.apacoust.2005.12.004

Jennings, P., & Cain, R. (2013). *A framework for improving urban soundscapes*. Applied Acoustics,74(2):293-299. http://doi.org/10.1016/j.apacoust.2011.12.003

Jeon, J. Y., & Hong, J. Y. (2015). *Classification of urban park soundscapes through perceptions of the acoustical environments*. Landscape and Urban Planning, 141:100–111. http://doi.org/10.1016/j.landurbplan.2015.05.005

Kang, J. (2010). *From understanding to designing soundscapes*. Frontiers of Architecture and Civil Engineering in China, 4(4):403–417. http://doi.org/10.1007/s11709-010-0091-5

Klaeboe, R., Kolbenstvedt, M., Fyhri, A., & Solberg, S. (2005). *The impact of an adverse neighbourhood soundscape on road traffic noise annoyance*. Acta Acustica United with Acustica,91(6):1039–1050. http://www.ingentaconnect.com/content/dav/aaua/2005/00000091/00000006/art00013?crawler=true

Krause, B. (1987). *The niche hypothesis: How animals taught us to dance and sing*. Whole Earth Review, 57. www.appohigh.org/ourpages/auto/2010/12/21/52074732/niche.pdf

Kuttruff, H. (2007). *Acoustics An introduction*. London ; New York :Taylor & Francis.

Liu, F., & Kang, J. (2016). *A grounded theory approach to the subjective understanding of urban soundscape in Sheffield*. Cities, 50:28–39. http://doi.org/10.1016/j.cities.2015.08.002

Mann, C. R., & Twiss, G. R. (1905). *Physics*. Scott, Foresman.

Marry, S., & Defrance, J. (2013). *Analysis of the perception and representation of sonic public spaces through on site survey, acoustic indicators and in-depth interviews*. Applied Acoustics,74(2):282–292. http://doi.org/10.1016/j.apacoust.2012.01.005

Matsinos, Y. G., Mazaris, A. D., Papadimitriou, K. D., Mniestris, A., Hatzigiannidis, G., Maioglou, D., & Pantis, J. D. (2008). *Spatio-temporal variability in human and natural sounds in a rural landscape*. Landscape Ecology, 23(8): 945-959. http://doi.org/10.1007/s10980-008-9250-7

Mendes, S., Colino-Rabanal, V. J., & Peris, S. J. (2011). Bird song variations along an urban gradient: *The case of the European blackbird (Turdus merula)*. Landscape and Urban Planning,99(1):51–57. http://doi.org/10.1016/j.landurbplan.2010.08.013

Moore, B. C. J. (2012). *Contributions of von Békésy to psychoacoustics*. Hearing Research, 293(1–2):51–57. http://doi.org/10.1016/j.heares.2012.04.009

Nega, T., Yaffe, N., Stewart, N., & Fu, W.-H. (2013). *The impact of road traffic noise on urban protected areas: A landscape modeling approach*. Transportation Research Part D: Transport and Environment, 23:98–104. http://doi.org/10.1016/j.trd.2013.04.006

Nemeth, E., & Brumm, H. (2009). *Blackbirds sing higher-pitched songs in cities: adaptation to habitat acoustics or side-effect of urbanization?* Animal Behaviour, 78(3):637–641. http://doi.org/10.1016/j.anbehav.2009.06.016

Nilsson, M. E., & Berglund, B. (2006). *Soundscape quality in suburban green areas and city parks*. Acta Acustica United with Acustica, 92(6):903–911. http://www.ingentaconnect.com/content/dav/aaua/2006/00000092/00000006/art00008

O'Connor, P. (2008). *The Sound of Silence: Valuing Acoustics in Heritage Conservation*. Geographical Research, 46(3):361–373. http://doi.org/10.1111/j.1745-5871.2008.00529.x

Öhrström, E., Skånberg, A., Svensson, H., & Gidlöf-Gunnarsson, A. (2006). *Effects of road traffic noise and the benefit of access to quietness*. Journal of Sound and Vibration, 295(1–2):40–59. http://doi.org/10.1016/j.jsv.2005.11.034

Pijanowski, B. C., Farina, A., Gage, S. H., Dumyahn, S. L., & Krause, B. L. (2011). *What is soundscape ecology? An introduction and overview of an emerging new science*. Landscape Ecology, 26(9):1213–1232. http://doi.org/10.1007/s10980-011-9600-8

Pijanowski, B. C., Villanueva-Rivera, L. J., Dumyahn, S. L., Farina, A., Krause, B. L., Napoletano, B. M., … Pieretti, N. (2011). *Soundscape Ecology: The Science of Sound in the Landscape*. BioScience, 61(3):203–216. http://doi.org/10.1525/bio.2011.61.3.6

Pinch, T., & Bijsterveld, K. (2011). *The Oxford Handbook of Sound Studies*. Oxford University Press.

Porteous, J. D., & Mastin, J. F. (1985). *Soundscape*. Journal of Architectural and Planning Research, 2(3):169–186. http://www.jstor.org/stable/43028767

Ratcliffe, E., Gatersleben, B., & Sowden, P. T. (2013). *Bird sounds and their contributions to perceived attention restoration and stress recovery*. Journal of Environmental Psychology, 36:221–228. http://doi.org/10.1016/j.jenvp.2013.08.004

Schafer, R. M. (1977). *The Tuning of the World*. Knopf.

Schafer, R. M., & Murray, R. (1969). *The new soundscape: a handbook for the modern music teacher*. BMI Canada Don Mills, Ont.

Scientific American (1884), 50(14): 218-219. Retrieved from https://archive.org/stream/scientific-american-1884-04-05/scientific-american-v50-n14-1884-04-05#page/n11/mode/2up

Slabbekoorn, H., & Peet, M. (2003). *Ecology: Birds sing at a higher pitch in urban noise*. Nature,424(6946):267–267. http://doi.org/10.1038/424267a

Slabbekoorn, H., & Ripmeester, E. A. P. (2008). *Birdsong and anthropogenic noise: implications and applications for conservation*. Molecular Ecology,17(1):72–83. http://doi.org/10.1111/j.1365-294X.2007.03487.x

Suárez, E., & Barros, J. L. (2014). *Traffic noise mapping of the city of Santiago de Chile*. Science of The Total Environment, 466–467:539–546. http://doi.org/10.1016/j.scitotenv.2013.07.013

Sueur, J., & Farina, A. (2015). *Ecoacoustics: the Ecological Investigation and Interpretation of Environmental Sound*. Biosemiotics, 8(3):493–502. http://doi.org/10.1007/s12304-015-9248-x

Swaddle, J. P., & Page, L. C. (2007). *High levels of environmental noise erode pair preferences in zebra finches: implications for noise pollution*. Animal Behaviour, 74(3):363–368. http://doi.org/10.1016/j.anbehav.2007.01.004

Thompson, E. A. (2004). *The Soundscape of Modernity: Architectural Acoustics and the Culture of Listening in America, 1900-1933*. MIT Press.

Truax, B. (1978). Handbook for Acoustic Ecology. Retrieved 1 March 2016, from http://www.sfu.ca/sonic-studio/handbook/

Truax, B. (2001). *Acoustic Communication*. Greenwood Publishing Group.

Vogiatzis, K. (2012). *Airport environmental noise mapping and land use management as an environmental protection action policy tool. The case of the Larnaka International Airport (Cyprus)*. Science of The Total Environment, 424:162–173. http://doi.org/10.1016/j.scitotenv.2012.02.036

Vogiatzis, K., & Remy, N. (2014). *From environmental noise abatement to soundscape creation through strategic noise mapping in medium urban agglomerations in South Europe*. Science of The Total Environment, 482–483:420–431. http://doi.org/10.1016/j.scitotenv.2013.07.098

Warren, P. S., Katti, M., Ermann, M., & Brazel, A. (2006). *Urban bioacoustics: it's not just noise*. Animal Behaviour, 71(3):491–502. http://doi.org/10.1016/j.anbehav.2005.07.014

Yamada, Y. (2006). *Soundscape-based forest planning for recreational and therapeutic activities*. Urban Forestry & Urban Greening, 5(3):131–139. http://doi.org/10.1016/j.ufug.2006.05.001

Zotero | Home. (n.d.). Retrieved 20 April 2016, from https://www.zotero.org/

Developing sustainable coastal areas: A comparison between the Netherlands and the United Kingdom

Liesbeth de Puydt, Anika Gladytz & Leena Karrasch

A U T H O R S I N F O

Liesbeth de Puydt* holds a Bachelor in Environmental Sciences, Open University of Heerlen, the Netherlands.

Anika Gladytz holds a Dr. rer. nat from the Faculty of Chemistry and Mineralogy, University of Leipzig, Germany

Leena Karrasch holds a Dr. rer. nat. from the Institute for Biology and Environmental Sciences, University of Oldenburg, Germany.

**email*: lef.depuydt@studie.openuniversiteit.be

A B S T R A C T

In this paper we compare current adaptation measures and decision-making processes, in accordance with the EU Floods Directive, in vulnerable coastal regions of the Netherlands and the United Kingdom. For both countries causes of climate change, current and future effects on the environment, impacts for society and responses of the society to the growing challenges are analysed and compared using the Drivers-Pressures-State-Impact-Responses (DPSIR) framework. The analysis shows that increasing flood risk and coastal erosion are the main problems for society and environment. The Netherlands and the United Kingdom follow similar decision-making paths to implement adaptation measures, yet due to geographical and geological differences, current adaptation measures in these countries are not overall the same. However, in order to generate proactive adaptation measures that take into account natural processes and stimulate prosperity levels, both countries use a transdisciplinary, multi-stakeholder approach.

K E Y W O R D S (in alphabetical order): *Climate change; DPSIR; European Floods Directive; Integrated Coastal Zone Management; The Netherlands; United Kingdom.*

1. Introduction

Coastal areas, constituting the demarcation between the land and the sea, are very complex systems affected by both terrestrial and marine processes. Coastal regions are characterized by high population densities and accompanying (conflicting) economic, social and environmental interests (Lescrauwaet et al. 2006). Furthermore, the possible effects of climate change put extra pressure on coastal regions (Nicholls et al. 2007).

In the last few decades, European coastal regions were traditionally protected by hard flood protection measures such as sea walls (called dikes), dams, tidal barriers, sheet pile

walls, groynes, and floodgates (Linares 2012). In order to develop sustainable European coastal regions, it is of great importance to follow integrated and participatory approaches. This includes to balance environmental, economic and social interests by taking a long-term view into account, to develop coastal infrastructure and spatial planning that are multi-functional and adaptable to changing conditions such as the effects of climate change, and to work in line with natural processes (da Vriend et al. 2014; Lescrauwaet et al. 2006). Hard measures alone will not be sufficient to create sustainable coastal areas. Furthermore, instead of using only reactive mitigation measures (attempts to reduce greenhouse gas (GHG) emissions and impacts of climate change on a global scale), it is crucial to develop proactive adaptation measures that take into account natural processes and stimulate prosperity levels (reduce vulnerability by reducing risk and impacts on local to regional scale) (da Vriend et al. 2014; Fischer et al. 2007; van Wesenbeek et al. 2014). Regarding a sustainable coastal development in accordance with Recommendation 2002/413/CE regarding the implementation of Integrated Coastal Zone Management (ICZM), the European Commission approved the EU Floods Directive (Directive 2007/60/EC) on the assessment and management of flood risks. The Floods Directive, linked to the Water Framework Directive, aims to reduce and manage the risks that floods pose to human health, the environment, cultural heritage and economic activity (Directive 2007/60/EC).

The Netherlands and the United Kingdom have a long history of coping with floods. Traditionally, the flood management policies of both countries used technological solutions to reduce flood risk by focusing on the construction of hard defence measures (Brown and Damery 2002; van Wesenbeeck et al. 2014). To better understand the changing views with respect to coastal protection and climate change, we analyse how two different European North Sea regions located in the Netherlands (Zeeland, Zuid-Holland, Noord-Holland, and Friesland) and the United Kingdom (estuaries of the Greater Thames area) are affected by the changes of climate change and how they respond to them. The comparison is done by using the Drivers-Pressures-State-Impact-Responses (DPSIR) framework (EEA 1999). The framework integrates natural and socio-economic information into a broad context of causality. The strength of the framework is that management problems can be analysed by structured cause-effect relationships: external drivers lead to pressures on natural and societal systems, the pressure affects the state of these systems, resulting in impacts which need (policy) responses (Ness et al. 2010). Although the DPSIR framework offers a generalized context, there is interest in its application to evaluate sustainability in European coastal regions and to support the decision-making

processes concerning the management of these regions (e.g. Atkins et al. 2011; Borja et al. 2006; Cave et al. 2003; Elliot 2002; Ness et al. 2010; Pirrone et al. 2005; Wamsley 2002).

The central aim of this paper is to identify suitable measures to adapt to the threats arising from climate change in the vulnerable areas of the coastlines of the United Kingdom and the Netherlands. To meet this aim, we determine (1) which threats and challenges arise or are expected to arise from climate change in the two areas (drivers and pressures), (2) which adaptation methods exist (state), (3) what the advantages, disadvantages, challenges and risks of these measures are (impact), and (4) what measures to deal with the problems are applied in the two regions with their specific social, ecological and political situations (response). We conclude with lessons that can be learned, based on the comparison of the two coastal regions, to counteract possible negative effects of climate change and to secure sustainable development in the future by combining traditional and new approaches.

2. Materials and methods

To analyse and structure the data from our literature review, the DPSIR -framework was applied to both case study regions. Therefore, socio-economic drivers, environmental pressures and the state of the coastal areas are determined and resulting impacts on human well-being as well as governmental and societal responses are delineated (Karageorgis et al. 2005). However, to attain the central aim of this research, the main focus is on the impacts that are related to climate change and the accompanying responses in accordance with the Floods Directive and ICZM. The final DPSIR framework provides the ability to compare the policy processes and the effectiveness of the adaptation measures of the two coastal regions towards sustainable development.

2.1 Case study areas

The comparative case study takes the Netherlands´ coastal provinces of Zeeland, Zuid-Holland, Noord-Holland and Friesland, and for the United Kingdom the region of South East England, including East Anglia, Essex, Kent and Outer London into account. Especially adaptation measures are taken on regional scale (Fischer et al. 2007). These regions deliver examples how particular programmes and policies work, and provide literature about quantitative and qualitative data for investigating similarities and differences how to develop sustainable coastal areas.

2.1.a The Netherlands

The geological development of the Netherlands was determined by a combination of erosion, transport and sedimentation processes. The Netherlands is located in the delta of the Rhine and Meuse rivers (de Moel et al. 2011).

The geological appearance of the Netherlands forced the floodplain inhabitants to live on artificial dwelling mounds since the 7th and 8th centuries. Additionally, the settlements were protected by small ring dikes. Increasing sea levels and population led to the building of a closed dike line, which started around 1100 A.D. (Knottnerus 2005). Today, about 65% of the population lives in areas that are protected by flood defences (de Moel et al. 2011). Furthermore, socio-economic developments in coastal regions have boomed in recent decades thus currently 80% of the GNP is potentially threatened by floods (Taal et al. 2006). Figure 1 shows the four coastal provinces of Zeeland, Zuid-Holland, Noord-Holland, and Friesland.

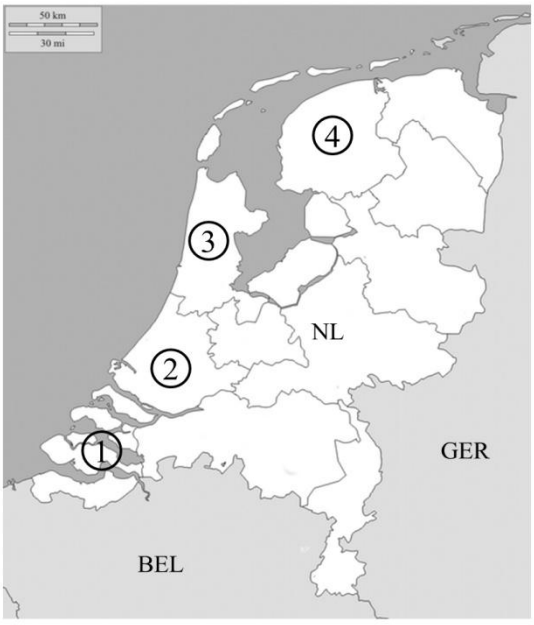

Figure 1: Coastal provinces of the Netherlands: 1) Zeeland, 2) Zuid-Holland, 3) Noord-Holland, and 4) Friesland.

2.1.b The United Kingdom

The South East of England is characterized by estuarine shores, such as the Greater Thames Estuary and the estuaries in Essex. These flat and low-lying estuaries comprise ecologically important coastal lagoons, salt marshes, wet grasslands and reedbeds (Esteves et al. 2014). Seventy five per cent of the property value that is located near the coastline of the United Kingdom is centred in London and the surrounding Thames tidal flood plain (Bingley et al. 2008). This study's focus will be on the region of South East England (Figure 2), including the counties of Kent, Essex, East Anglia and Outer London which belong to the most vulnerable regions.

Figure 2: *Estuaries of the Greater Thames area in the United Kingdom (van der Wal and Pye 2004).*

2.2 The DPSIR framework applied to the case study regions

In 1999, the European Environmental Agency (EEA) developed the 'Drivers-Pressures-State-Impact-Responses' (DPSIR) framework, based on the previously developed 'Pressure-State-

Response' (PSR) framework of the Organisation for Economic Co-operation and Development (OECD) (Camanho et al. 2010; Martins et al. 2012). The DPSIR framework is based on a concept of causality (Pirrone et al. 2005) and describes the relationships between human activities and the environment. As described in Carr et al. (2007), the 'drivers' in DPSIR comprise driving forces, that are factors or processes which shape human activities and have effects on the environment (such as the use of fossil fuels or change in population). The 'pressures' directly result from the 'drivers' and are described by human activities impacting the environment (such as GHG emissions or land use). 'Pressures' influence the 'state' of the environment and condition future trends as well. The 'impacts' describe changes in the state that influence human well-being (such as impacts of climate change). On institutional level, efforts undertaken to address the changes in 'state' are called 'responses' (such as fulfillment of policy goals or projects to find innovative solutions).

In general, the DPSIR is a useful framework to capture problems caused by human activities and to identify responses as sufficient solutions (Pironne et al. 2005). For example, the DPSIR approach has been used to identify the impacts of socio-economic developments on the state of European marine waters in order to assess the most suitable responses in accordance with the Water Framework Directive and Floods Directive objectives (e.g. Borja et al. 2006; Karageorgis et al. 2005; Pirrone et al. 2005). As proposed by Atkins et al. (2011), a DPSIR cycle (Figure 3), which highlights the multiple interactions between the individual elements of the DPSIR framework, has been used in this paper, and the different steps of the DPSIR framework are based on the definitions of Carr et al. (2007), EEA (2002), and FAO (1999).

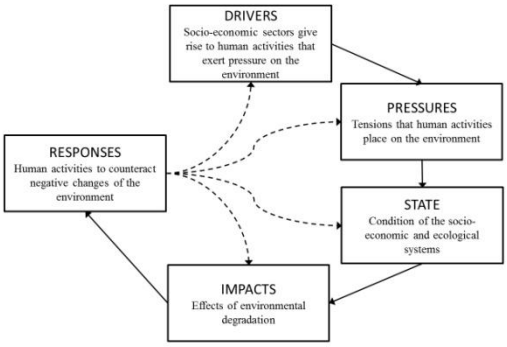

Figure 3: *Causal links in the generic DPSIR framework.*

In order to compare the case study regions, a set of indicators (Table 1) was used to analyse the different components of the DPSIR framework. The indicators have been selected because GHG emissions and intensification of land use are two major pressures making a sustainable development of coastal areas necessary. These pressures are driven by human needs (here described by the demand of fossil fuels and population balance and density). The state of the environment is affected – climate change as well as coastal erosion- and hard defence measures lead to impacts such as groundwater salinization, disappearance of salt marshes, biodiversity loss and water

management challenges. The society and institutions need to find new ways to adapt to these impacts and respond: in terms of recognition that climate change has an impact, doing scientific research, following goals of ICZM and the Flood Directive and increase the awareness of the society. These indicators are used as qualitative or quantitative parameters to characterize the current condition of an environmental aspect or its change over time. We analysed statistical data to compare the different indicators provided by i.e. Eurostat or the World Bank. Whenever possible, regional data were used. In the absence of regional data, national data of the United Kingdom and the Netherlands have been analysed. Furthermore, we screened policy documents to analyse the flood risk management strategies provided by i.e. the Government of the Netherlands or Environmental Agency and provided practical response-examples from different national institutions.

3. Results

Figure 4 illustrates the relationships and multiple interactions of the DPSIR elements. The drivers of change lead to pressures which influence the current state of the case study regions. As described in detail in the following paragraphs, this causes impacts on habitats and water management issues. In order to cope with these impacts, (policy) responses are necessary to tackle possible impacts of climate change, and to secure and develop innovative flood protection measures to make settlements and land use possible.

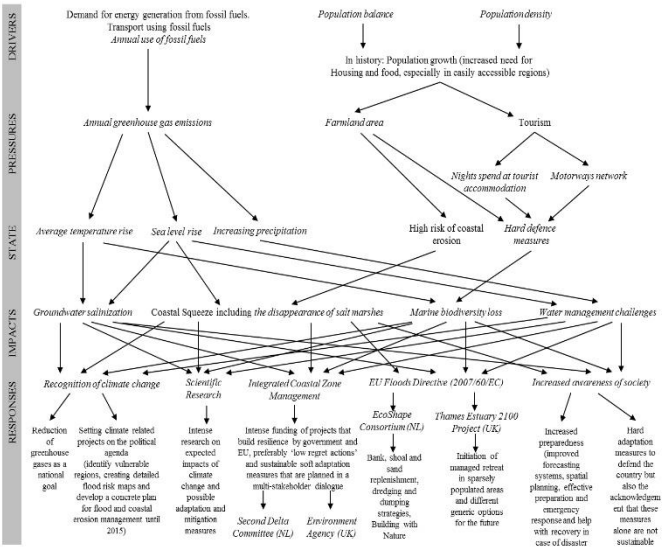

Figure 4: *Multiple interactions between DPSIR elements applied to the case study areas. Italics delineate the indicators.*

3.1 Drivers

The indicator *annual use of fossil fuels* is directly related to the global emissions of GHG that enhance climate change (IPCC 2014). The fossil fuel energy consumption of the Netherlands comprised 91.5%, and of the United Kingdom 85.2%, of the total annual energy consumption in the year 2012 (World Bank 2015a). These percentages are relative since the actual annual final consumption in the United Kingdom is almost twice as high as the annual final consumption in the Netherlands (Table 2).

Table 1: *Selected indicators to identify the major DPSIR elements for the case study areas.*

Drivers	Annual use of fossil fuels	Population balance	Population density		
Pressures	Annual greenhouse gas emissions	Farmland area	Nights spent at tourist accommodation	Motorways network	
State	Average temperature rise	Sea level rise	Increasing precipitation	High risk of coastal erosion	Hard defence measures
Impacts	Groundwater salinization	Coastal squeeze including disappearance of salt marshes	Marine biodiversity loss	Water management challenges	
Responses	Recognition of climate change	Scientific research	Integrated Coastal Zone Management, Second Delta Committee (NL), Environment Agency (UK)	EU Floods Directive (2007/60/EC), EcoShape Consortium (NL), Thames Estuary 2100 project (UK)	Increased awareness of society

Table 2: *Energy balances (2012) of the United Kingdom and the Netherlands in thousand tonnes of oil equivalent (according to International Energy Agency 2015a; 2015b).*

Energy balances 2012 (in thousand tonnes of oil equivalent)	**Coal**	**Crude oil**	**Oil products**	**Hydro**	**Geo-thermal and solar**	**Biofuels and waste**	**Elec-tricity**	**Heat**	**Total**
United Kingdom									
Total primary energy supply[a]	38873	73158	-14665	455	1941	6753	1036	0	192231
Total final consumption[b]	2377	0	51716	0	154	1967	27311	1232	127570
Industry	1764	0	4018	0	0	416	8412	795	23970
Transport	9	0	37579	0	0	930	352	0	38870
Other[c]	604	0	3707	0	154	621	18547	438	57857
Non-energy use[d]	0	0	6412	0	0	0	0	0	6873

Table 2 (*continued***)**

Energy balances 2012 (in thousand tonnes of oil equivalent)	**Coal**	**Crude oil**	**Oil pro-ducts**	**Hydro**	**Geo-thermal and solar**	**Biofuels and waste**	**Elec-tricity**	**Heat**	**Total**
The Netherlands									
Total primary energy supply[a]	8199	60415	-29492	9	500	3675	1471	0	78578
Total final consumption[b]	878	4405	22490	0	37	861	9157	1917	61051
Industry	645	2275	511	0	0	87	2985	1057	12534
Transport	0	0	10867	0	0	335	154	0	11373
Other[c]	11	0	795	0	37	439	6017	860	22468
Non-energy use[d]	222	2130	10317	0	0	0	0	0	14675

[a] Total primary energy supply is made up of the sum of indigenous production, import, export, international marine and aviation bunkers and stock changes (i.e. the difference between opening stock levels at the first day of the year and closing levels on the last day of the year).

[b] Total final consumption is the part of the total primary energy supply that is consumed after transfers, transformation processes and energy industry own use.

[c] Energy for residential, commercial and public services, agriculture, forestry, fishing and non-specified.

[d] Non-energy use comprises fuels that are used as raw materials in the different sectors and are not consumed as a fuel or transformed into another fuel.

Table 3: *Population balance and population density between 2002 and 2013 of the Netherlands and the United Kingdom (according to Eurostat 2015d; 2015e; World Bank 2015b).*

Population	**2002**	**2013**		**2002**	**2013**
The Netherlands	16,105,285	16,779,575	United Kingdom	59,239,564	63,905,297
Friesland	636,184	646,862	East Anglia	2,188,252	2,419,478
Noord-Holland	2,559,477	2,724,300	Essex	1,620,694	1,747,002
Zuid-Holland	3,423,780	3563,935	Kent	1,585,163	1,756,588
Zeeland	377,235	381,077	Outer London	4,474,732	5,052,557
Population density (persons per km^2)	**2002**	**2013**		**2002**	**2013**
The Netherlands	478	498	United Kingdom	245	264
Friesland	190	194	East Anglia	175	193,3
Noord-Holland	960	1025	Essex	443	478
Zuid-Holland	1214	1272	Kent	426	472
Zeeland	209	214	Outer London	3578	4058

Table 3 delineates the *population balance* and the *population density* of the provinces and the counties that comprise the coastal regions between 2002 and 2013. Noord-Holland, Zuid-Holland, and Outer London have the highest population densit (Eurostat 2015d; World Bank 2015b). The population balance is connected with the need for infrastructure, land, food, employment, public services, motorways, flood protection and housing. The *population density* (Table 3) is a second important indicator. All of the case study regions show an increase in population density. Noord-Holland and Zuid-Holland show large population densities compared to the other regions and Outer London stands out with a population density of 4,058 persons per km^2 (Eurostat 2015e). A large population density enhances the importance of ICZM in order to fulfil the human needs in a sustainable way.

3.2 Pressures

According to the IPCC (2014), anthropogenic GHG emissions depending on economic growth, fossil fuel use and population growth, are extremely likely the dominant cause of the observed warming since the mid-20^{th} century. Consequently, the pressure -indicator is the *annual emission of greenhouse gases* in the Netherlands and the United Kingdom. Through the Kyoto Protocol, both countries were committed to reducing their GHG emissions between 2008 and 2012. The Netherlands was forced to reduce its GHG emissions by 6% relative to the baseline year 1990. For the United Kingdom, the target was set on a 12.5% decline relative to the baseline year (EEA 2010). Both countries achieved their Kyoto Protocol targets, with the United Kingdom even exceeding it (see Table 4).

Table 4: *Greenhouse gas emissions between 1990-2012 of the United Kingdom and The Netherlands in CO_2-equivalents (according to EDGAR 2015).*

Greenhouse gas emissions (in CO_2-equivalents) **by year**	United Kingdom	The Netherlands
1990	777,244.23	224,468.09
1995	728,336.09	235,053.00
2000	673,897.41	220,320.00
2005	659,108.09	217,084.00
2010	609,586.56	212,418.45
2012	585,779.78	195,873.76

The *farmland area* in the Netherlands increases whereas the United Kingdom shows a decline with the exception of Outer London (Table 5). Population growth and changes in socio-economic interests (increasing tourism and the accompanying need for infrastructure) increase the demand for food and the need for land. The intensification of farming techniques (fertilisers, pesticides) leads to environmental

damages (Lescrauwaet et al. 2006). This process has introduced other environmental problems such as high risk of coastal erosion.

The number of nights spent at tourist accommodation emphasizes the economic importance of tourism in the case study regions but it also represents the pressure that tourists exert on the environment. An increasing number of tourists requires an increasing amount of infrastructure and land. Furthermore, the consumption of energy and water as well as the production of waste peak during the high season (Lescrauwaet et al. 2006). In both countries, there is a general increase of the number of nights spent at tourist accommodation (Table 5). However, a decline can be ascertained in some of the case study regions.

In order to attain sustainable development in the coastal regions, it is important to meet traffic requirements in such a way that reachability and safety are enhanced. Table 5 shows the change in *the motorways network* in the United Kingdom and the Netherlands. The Netherlands shows an increase in the motorways network whereas the United Kingdom shows stagnation between 2002 and 2013. An increase of the motorways network and the associated traffic can affect the environment and human health negatively. On the other hand, it increases reachability of the coastal areas, which makes the motorways network a necessary infrastructure to amplify economic activities (Lescrauwaet et al. 2006).

3.3 State

The state -indicators mainly focus on observed climate changes in the case study regions. A socio-economic dimension is added to the state through the description of the prevailing measures to counteract flooding in the United Kingdom and the Netherlands.

The Netherlands is characterized by *an average temperature rise* that is 1.7°C higher than a century ago (PBL Netherlands Environmental Assessment Agency 2013). In the United Kingdom, the average temperature is 1°C higher than 100 years ago. The temperature in both countries is rising faster than the global trend (Jenkins et al. 2008).

Sea level rise directly affects the development of intertidal habitats such as mudflats and salt marshes. In natural conditions, these intertidal habitats are able to counteract sea level rise through inland migration and vertical accretion. However, inland migration is often hindered by the presence of hard defence measures and the vertical accretion is hindered by a human-induced lack in sediment supply (Esteves et al. 2014). In the Netherlands, the average sea level has risen by 20 cm during the past century. Due to human interventions, such as dredging operations and the construction of dikes and dams in the past, the regional rise in sea level varies considerably (PBL Netherlands Environmental Assessment Agency 2013). Consequently, sea level in this region has risen by 13 cm whereas Zuid- and Noord-Holland

have shown an average sea level rise of 24 cm throughout the last century (PBL Netherlands Environmental Assessment Agency 2013). In the United Kingdom, the average sea level has risen by 13 cm during the past century (Lowe et al. 2009). The land mass of the United Kingdom is moving as a result of the melting of the ice-sheet since the end of the last ice age. Consequently, there are regional differences in the average sea level rise since there is a general upward land movement in the north and a downward movement in the south. The latter enhances flood risk challenges in the low-lying coastal areas along the southeast coast from Lincolnshire to the Thames estuary (Lowe et al. 2009).

Increasing precipitation puts a lot of pressure on drainage systems. Low-lying coastal areas are particularly vulnerable to flooding since gravity drainage depends on the difference in elevation between the drained area and the area to which the water flows. Consequently, low-lying coastal areas are characterized by forced drainage through pumps (Titus et al. 1987). Increased precipitation may overload these drainage systems in the future, inducing surface water flooding and sewerage flooding. With rising sea levels, the time in which the water can be naturally discharged by gravity into the sea will decrease. Consequently, more water has to be actively pumped into the sea, which is very cost-intensive. During the last century, a significant precipitation increase has been observed in the Netherlands (Daniels et al. 2014): both mean and extreme precipitation accrued on seasonal and annual time scales for the period 1951-2009. The highest increase was noticed during the last 30 years. According to de Leeuw et al. (2015), the United Kingdom is located at the downstream end of the North Atlantic storm-track and the country is characterized by large variations in precipitation. There exist a wide variety of studies investigating the emergence of trends in the UK precipitation on different timescales (e.g. Hand et al. 2004; Jones and Conway 1997; Maraun et al. 2008; Osborn et al. 2000). Most of these studies conclude that the annual mean precipitation in the United Kingdom has not changed since recording started in 1766. Nonetheless, large differences were observed in seasonal precipitation totals, indicating a trend of increased precipitation in the winter (and to a lesser extent in autumn and spring) and a decrease of precipitation in the summer.

In both countries, there is a *high risk of coastal erosion.* Coastal erosion is a natural phenomenon: due to an imbalance in sediment supply and sediment drain, scouring in dunes or cliffs may appear. Natural activities such as wind, waves, storms, near-shore currents and weathering processes influence coastal erosion (Safecoast 2008). However, hard defence measures, land claim, river water regulation works (dams), dredging, gas mining, vegetation clearing and water extraction are human actions that enhance coastal erosion (Eurosion 2004). Furthermore, the changing state of the climate

and sea level rise put extra pressure on the, originally natural, coastal erosion processes (Safecoast 2008). However, it remains difficult to quantify to what extent human activities and

Table 5: *Pressure indicators; Farmland area in hectare, nights spent at tourist accommodations and motorways network in kilometre (according to Eurostat 2015a; 2015b; 2015c).*

Farmland (ha)	**2005**	**2007**		**2005**	**2007**
The Netherlands	2.035.230	2.074.800	United Kingdom	16.839.770	17058.920
Friesland	241.490	247.930	East Anglia	1.004.790	990.180
Noord-Holland	145.000	148.490	Essex	257.130	256.210
Zuid-Holland	145.770	151.190	Kent	241.400	244.610
Zeeland	122.850	124.730	Outer London	11.870	12.680
Nights spent at tourist accommodation[a]	**2002**	**2012**		**2002**	**2012**
The Netherlands	82.371.500	84.050.408	United Kingdom	263.769.000	303.564.528
Friesland	5.312.300	4.625.356	East Anglia	11.060.000	13.755.880
Noord-Holland	17.161.700	19.961.251	Essex	2.630.000	2.273.249
Zuid-Holland	8.581.200	8.142.256	Kent	4.642.000	5.555.577
Zeeland	7.647.100	7.226.760	Outer London	not available	15.920.757
Motorways (in km)	**2002**	**2013**		**2002**	**2013**
The Netherlands	2516	not available	United Kingdom	3611	not available
Friesland	180	201	East Anglia	48	48
Noord-Holland	277	290	Essex	82	82
Zuid-Holland	340	362	Kent	170	170
Zeeland	79	68	Outer London	60	60

[a] Tourist accommodations include hotels, holiday and other short-stay accommodations, camping grounds, recreational vehicle parks and trailer parks

global warming influence coastal erosion (Nicholls et al. 2007). Table 6 delineates the coastal erosion in the Netherlands and the United Kingdom in 2001. 18% of the Netherlands' coastline is affected by coastal erosion, whereas 27% of the coastal area in the United Kingdom was affected by erosion in 2001. The steady increase in coastal erosion might affect flood protection, property loss, tourism, historic landmarks, industrial development and ecosystems. Acknowledging this problem, the European Commission proposed in 2004 a number of recommendations to improve coastal erosion management (Mulder et al. 2011). The key finding is that a more strategic, proactive approach is needed for a sustainable development in coastal areas that are characterized by a shortage of space and sediment supply (Mulder et al. 2011).

Table 6: *Extend of coastal erosion (2001) in the Netherlands and the United Kingdom in km. (according to Salman et al. 2004).*

	United Kingdom	**The Netherlands**
Total length of the coastline	17,381	1,206
Eroding coastline (protected and unprotected)	3,009	134
Artificially protected coastline	2,373	146
Eroding coastline in spite of protection	677	50
Total coastline impacted by coastal erosion	4,705	230

The Netherlands and the United Kingdom show a long history of coping with flooding from both tidal and fluvial sources (e.g. Brown and Damery 2002; van Wesenbeeck et al. 2014). Flood management policies of both countries traditionally favoured technological solutions to reduce flood risk by focusing on the construction of *hard defence measures* (Brown and Damery 2002; van Wesenbeeck et al. 2014). In 1953, both countries were startled by a major storm surge with a catastrophic outcome: 2,100 people and 200,000 animals died, a total of 2,500 km^2 of land was flooded and 120,000 people needed to be evacuated (Safecoast 2008). This devastating storm surge stimulated the beginning of intensive reinforcement of flood defences in both countries. At that time, policy processes in both counties were technocratic as decisions were based on technological knowledge (Brown and Damery 2002). In the Netherlands, most of the flood measures were taken in the Rhine-Meuse delta since the province of Zeeland was the most affected by the 1953 storm surge. After the government approbated the advice of the Delta Committee in 1958, the Delta Law formed the legal base to start the infrastructural pursuits of the Delta Works (Deltawerken 2004). By 2010, all the dikes were reinforced, the coastline was intensely shortened and three movable storm surge barriers, one bridge and nine dams were built. The Delta Works generate a minimum

safety standard of a flooding probability of 1/2,500 years and a maximum safety standard of 1/10,000 years (Klijn et al. 2004). The former estuarine inlets have become isolated fresh- and saltwater lakes providing new services such as flood safety, opportunities for tourism and freshwater supply for agriculture (van Wesenbeeck et al. 2014). The Delta Works were innovative at the time of construction but the upcoming environmental degradation was not foreseen. In the United Kingdom, the east coast was the most struck by the 1953 storm surge (Lumbroso and Vinet 2011). The government decided that the best solution to protect London was building a tidal surge barrier with movable gates across the Thames, raising the river banks and pursuing a good system of flood warnings (Lavery and Donovan 2005). The Thames Barrier and Flood Prevention Act provided the legal base to start the construction of the Thames Barrier and the accompanying defences. By 1982 the Thames Barrier was operational. According to Lavery and Donovan (2005), the Thames Barrier currently offers not only flood protection for the next decades, but also the opportunity to 'buy time' to consider possible strategies for long-term sustainable flood management. London is expected to be protected against floods with an annual probability of 1/1,000 until the year 2030 (Lavery and Donovan 2005). Regarding the impacts of climate change, only hard defence measures will not be sufficient to ensure flood safety.

3.4 Impacts

Groundwater salinization in the Netherlands occurs mainly in the low-lying coastal areas. The construction of hard defence measures in combination with drainage activities in coastal areas resulted in land subsidence (Pauw et al. 2014). Consequently, polders are located below mean sea level and lateral saltwater intrusion occurs. According to Oude Essink et al. (2010), salt water intrusion is a problem in the low-lying areas in a broad coastal strip of about 10 km. Freshwater supply in the South East of England is limited due to large population density and relatively low annual rainfall. Furthermore, almost 120,000 new homes are planned on either side of the Thames Estuary to the east of London. This puts extra pressure on the (already scarce) freshwater supplies in the area and will enhance saltwater intrusion (EA 2006). A lower river discharge in the summer and an increasing sea level will accelerate the saltwater intrusion in both countries. This increased saltwater intrusion will reduce the availability of both fresh surface water and groundwater. Furthermore, it will have a negative impact on agricultural activities, since high salinity in the root zone can induce crop damage and salt intrusion contaminates drinking water for cattle (PBL Netherlands Environmental Assessment Agency 2013).

Salt marshes are located at the interface between marine and terrestrial zones in low-energy environments within estuaries (Allen 2000; Foster et al. 2013). Both countries face

problems of coastal squeeze including the disappearance of salt marshes. Coastal squeeze describes the disruption of the natural dynamics of salt marshes caused by hard defence measures, such as dikes, which hinder the inland migration of the salt marsh (Pontee 2013). Sea level rise in combination with decreased sediment availability lead to changes of these valuable ecosystems (Ma et al. 2014). Since the adoption of the Convention on Wetlands of International Importance in Ramsar in 1971, the importance of saltmarshes for biodiversity and human well-being was acknowledged (Foster et al. 2013). Saltmarshes offer habitats for migratory and wintering birds and they are used as spawning and nursery areas. Furthermore, salt marshes are able to dampen wave and tidal energy and to improve water quality by fixing the excess of nitrogen (van der Wal and Pye 2004). In the Netherlands, salt marshes can be found in the regions of Friesland and Zeeland. Not all salt marshes developed naturally: in order to reclaim land, sedimentation was actively stimulated on the seaward side of the dikes through drainage systems in the mudflats and through the construction of brushwood groynes (Dijkema et al. 2011). The construction of the Delta Works had a large impact on the salt marsh area in Zeeland. Due to damming, former saltwater areas changed to freshwater lakes leading to the disappearance of salt marshes in the 1970s (de Jong et al. 1994). After the storm surge barrier in the Oosterschelde was finished in 1986, the salt marsh area decreased dramatically by more than 50% over the following 15 years. Although accretion rates are lower than the pre-surge barrier period, current research by Ma et al. (2014) reveals that remaining salt marshes are expected to survive under the present sea level rise rate. According to van der Wal and Pye (2004), lateral erosion of the salt marshes of the estuaries in the Greater Thames area started at the beginning of the 20th century. There are several causes for the erosion of the salt marshes: land claim, embankment constructions and a continuous rise of extreme water levels. However, all the salt marshes in the Greater Thames estuary were able to keep pace with rising sea levels during the last century through vertical sediment accretion. Furthermore, van der Wal and Pye (2004) concluded that changing wind and wave magnitude has been the determining factor for enhanced lateral marsh erosion and vertical accretion in the Greater Thames area during the last decades.

Impacts on marine biodiversity loss are caused by changing sea temperature, which will become increasingly profound in the future (Hopkins et al. 2007). An increasing water temperature interferes with timings of seasonal events, leading to a disturbance of synchronicity between species and the availability of food (Hopkins et al. 2007). Furthermore, an increasing water temperature generates suitable conditions for alien warm-water species, leading

to changes in the native community structure. For example, Weijerman et al. (2005) found a positive relationship between increased water temperature and an increase in numbers of grouper (*Dicentrarchus labrax*), solenette (*Buglossidium luteum*), small weever (*Trachinus vipera*) and scaldfish (*Arnoglossus laterna*) in the North Sea. However, the increased water temperature in these regions caused the disappearance of the plaice (*Pleuronectes platessa*), which is a commercially important species (van Keeken et al. 2007).

An increasing water temperature provoked similar species shifts in the United Kingdom. Arnott and Ruxten (2002) found a negative relationship between sand-eel (*Ammodytes marinus*) recruitment and higher winter sea surface temperatures in the United Kingdom. The low recruitment of sand-eels has an impact on predator species that feed on them. Consequently, sand-eel feeders like kittiwakes (*Rissa tridactyla*) have shown a low breeding success in winters with higher winter sea surface temperature (Frederiksen et al. 2007). Furthermore, the numbers of warm-water fish such as stingrays (*Dasyatidae*) and triggerfish (*Balistes*) increased in the coastal waters of southern Britain whereas numbers of cold-water species such as the acorn barnacle (*Balanus perforatus*), dabberlocks alga (*Alaria esculenta*) and the zooplankton species (*Calanus finmarchicus*) declined (IACCF 2010).

The changing state of the climate has an impact on the current flood defence measures and *provides water management challenges* of the United Kingdom and the Netherlands. The construction of the flood defence measures after 1953 were innovative at that time but some of them do not meet the current safety standards anymore. Consequently, dikes and dunes of the Netherlands are currently reinforced and in Zeeland, rubble and steel slag deposits are needed to strengthen the dikes. During the construction of the Thames Barrier in the United Kingdom, it was anticipated that the barrier needed to cope with sea level rise resulting from a natural decrease of land levels. According to the EA (2014) further protection will be needed in the short term (25 years), medium term (the following 15 years) and long term (to the end of the century) in order to safeguard the flooding safety standards. In the Netherlands, large low-lying coastal areas are used for agriculture and human settlement. In these regions, precipitation drains into small canals and flows towards the downstream pump station (van Overloop 2006). Today, the best solution to cope with increased precipitation in the Dutch polders is to increase pumping activities (Ritzema and Stuyt 2015). However, the combined changes in precipitation, sea level rise, subsidence and urbanization will require more fundamental structural changes (Ritzema and Stuyt 2015). Consequently, the Netherlands and the United Kingdom face great challenges concerning their water management

in the future. According to the Greater London Authority (2005), surface water flooding is probably the greatest short-term climate risk to London. Increased winter rainfall, increased heavy rainfall events, poor maintenance of drains and gullies, reduced water permeability of the soil caused by use of impermeable materials and the fact that London drainage systems are designed for high-frequency, low-volume rainfall amplify the probability of surface water flooding in London.

3.5 Responses

Recognition of climate change and accompanying scientific research towards adapting the effects is important in both regions. Along with the development of the Intergovernmental Panel on Climate Change in 1988 and the establishment of the United Nations Framework Convention on Climate Change (UNFCCC) in Rio de Janeiro in 1992, climate policies in the Netherlands and the United Kingdom started to evolve. In 1997, the Kyoto Protocol was adopted, which entered into force in 2005. This international treaty emanated from the UNFCCC and obligates developed countries (including the Netherlands and the United Kingdom) to foster climate change mitigation by reducing their GHG emissions. In the Netherlands, the Ministry of Housing, Spatial Planning and the Environment (2006) launched the 'Initial Report of The Netherlands, under the Kyoto Protocol' and in the United Kingdom, the Department of the Environment, Transport and the Regions (2000) launched its 'Climate Change Programme' in response to the Kyoto Protocol. Furthermore, the Dutch climate research community developed two transdisciplinary research programmes in order to attain a climate-compatible development: 'Climate changes Spatial Planning' (2004-2012) and its successor 'Knowledge for Climate' (2008-2014). The two programmes focused on gathering scientific and applied knowledge. The 'Knowledge for Climate' programme designated eight areas in the Netherlands that are vulnerable to the effects of climate change. Two of them comprise the coastal areas of Zeeland and Friesland. In all of the eight regional hotspots, transdisciplinary research was conducted concerning different themes including flood protection, fresh water supply and water quality, governance, adaptation and policy instruments (Kennis voor Klimaat 2015).

In the United Kingdom, the work of the Climatic Research Unit of the University of East Anglia, founded in 1972, played a major part in navigating the study of climate change and in setting climate change on the political agenda. In order to mitigate or adapt to the possible effects of climate change, the Tyndall Centre for Climatic Change Research was founded in 2000, including scientists, economists, engineers, social workers, policy advisors and business stakeholders in a transdisciplinary manner to

develop sustainable responses to climate change (Tyndall Centre 2015).

3.5.a Integrated Coastal Zone Management (ICZM) Recommendation and the EU Floods Directive

Before the Earth Summit in 1992 in Rio de Janeiro, European policies in coastal zones were predominantly reactive and issue-oriented (Safecoast 2008). After the adoption of ICZM as one of the principal recommendations of Agenda 21 at the Earth Summit, the ICZM concept gained prominence and political legitimacy (Queffelec et al. 2009). The ICZM recommendation takes into account the serious threats to the coastal regions (Recommendation 2002/413/CE). The main goal of this recommendation is to guide the European coastal zones towards more sustainable scenarios by facilitating the links between economic, social and environmental European Directives and policies (Lescrauwaet et al. 2006). Sorensen (1993, p. 49) defines ICZM as '*a dynamic process in which a coordinated strategy is developed and implemented for the allocation of environmental, socio-cultural, and institutional resources to achieve the conservation and sustainable multiple use of the coastal zone*'. The ICZM process is characterized by vertical integration across local, regional, national and international government levels and by horizontal integration across different sectors. The traditional top-down approach is gradually substituted by a bottom-up governance approach, where consideration is given to key stakeholders and communities in the decision-making process (Queffelec et al. 2009).

The Floods Directive is an integrated policy instrument that targets ICZM. Its aim is to reduce and manage the risks that floods pose to human health, the environment, cultural heritage and economic activities (Directive 2007/60/EC). It commits all member states to identify vulnerable regions by 2011, draw flood risk maps by 2013 and establish flood risk management plans. The Floods Directive will be carried out in accordance with the Water Framework Directive and, as proposed by ICZM, member states will need to allow public participation in the preparation of the flood risk management plans (Directive 2007/60/EC).

Practical examples to fulfil the goals of ICZM and the Floods Directive are the *Second Delta Committee* and *EcoShape consortium* in the Netherlands, and the *Environment Agency (EA)* and *Thames Estuary 2100* project in the United Kingdom.

In the Netherlands, the Dutch Cabinet founded the *Second Delta Committee* in 2007 to come up with recommendations to avoid a disaster (Verduijn et al. 2012) and to delineate long-term solutions concerning flood protection and freshwater management (Deltacommissie 2008). Different framing strategies to create (public and political) awareness and support in order to influence the public agenda and the

climate adaptation policy were used (Verduijn et al. 2012). In 2008, the Second Delta Committee was disbanded but the government accepted its advice: since 2012, the Delta Act forms the legal base. The Delta Programme is a national, transdisciplinary enterprise in which central government, provincial and municipal authorities, water boards, civil-society organisations, business communities and scientific organisations are congregated, with a two-fold aim: providing protection against flooding now and in the future, and ensuring freshwater supplies (Government of the Netherlands 2015). The programme uses a phased model of decision-making in which uncertain long-term developments are taken explicitly and transparently into account, called the Adaptive Delta Management model (Marchand and Ludwig 2014). The results of Adaptive Delta Management within the Delta Programme are used to meet the Floods Directive (Government of the Netherlands 2015).

In the United Kingdom, many coastal bodies were formed as a consequence of the Earth Summit in Rio de Janeiro in 1992. Their goal was to establish an effective and holistic management system to ensure a sustainable development of the individual sections of the coastline (French 2004). The *Environment Agency* (EA) was founded through the Environment Act of 1995. This was the first time that all environmental issues were treated together by one agency with the goal of ensuring a sustainable development of the country (Jewell and Steele 1996). The EA is responsible for flood risk management arising from the main rivers and the sea. It coordinates, plans, and finances measures to reduce either the likelihood or the impacts of floods. Therefore, the EA is also responsible for flood warnings and flood risk maps to increase awareness of the public. Current policies of the EA are influenced and guided by the Floods Directive. By now, there are detailed maps publicly available about the flood risks in all areas that are situated close to rivers or the sea (EA 2015a). The EA explicitly works together with the government, communities, individuals, voluntary groups and private and public sector organizations. The goal is to establish a partnership between the authorities and local stakeholders (Stojanovic and Barker 2008). Next to stakeholder participation the following general principle should be fulfilled when measures are planned in the UK: because of the large uncertainty in climate projections, all long-term measures need to be flexible, i.e. it should be possible to adapt them quickly to any future scenario. Best suited to fulfil this criterion are so-called “low regret” actions. These are measures that are accompanied with benefits for today’s society and that can at the same time run under any future conditions.

The *EcoShape Consortium* in the Netherlands, an inter- and transdisciplinary multi-actor network, deals with the unforeseen

problems (such as erosion, eutrophication) that arose after the termination of the first Delta Works, and emphasizes the implementation of flexible soft protection structures in harmony with the sea (Waterman 2010). The Netherlands currently uses the 'Building with Nature' principle in order to develop sustainable coastal areas. This is in line with the Floods Directive, which focuses on flexible, sustainable solutions (Directive 2007/60/EC). Several flood risk measures have been implemented due to the EcoShape Consortium. The first measure was sand nourishment to counteract erosion at a large tidal flat in Zeeland (da Vriend et al. 2014). The second measure started in 2009 and is based on the use of Pacific oyster reefs to protect tidal flats and dispel wave energy in Zeeland (Jones et al. 1994). Oysters are able to combat erosion as they protect the underlying sediment against efflux. The first monitoring has shown that the tidal flats show no erosion, whereas the unprotected tidal flats show 2-3 cm erosion per year (da Vriend et al. 2014). A third measure is the construction of the Delfland sand engine on the Holland coast in 2011. Twenty million m^3 of sand were placed in one location, in order to be gradually redistributed along the shore by wind waves and currents. This innovative approach should counteract erosion for the next 20 years while it also provides new possibilities for nature and recreation (da Vriend et al. 2014). The main features of the preferential strategies for flood risk management in the different regions of the Netherlands are summarized in Table 7.

The *Thames Estuary 2100* project (TE2100) is a comprehensive action plan to manage flood risk (EA 2012). The plan delineates recommendations and actions to manage flood risk based on a multi-stakeholder collaboration. The TE2100 project delineates four generic estuary-wide options with accompanying sub-options (Table 8) to manage flood risk. Nevertheless, the efficiency and reliability of barriers are generally threatened by inundation from river water (e.g. after heavy rain or ice melting) and from local floods when the present drainage networks are overwhelmed. Therefore, the EA supports sustainable drainage systems, which reduce the risk of floods resulting from rain water. These are replications of natural systems (e.g. basins, rain gardens, reed beds) that collect, store and clean the water before they slowly release it. Hard measures are combined with other adaptation and mitigation strategies. One of the most important alternatives is better land management, which often includes managed realignment whereby land with low population density (for instance farmland) is converted to salt marshes and natural flood plains (French 2006; Turner et al. 2007). An example for realignment projects is the "Essex Wildlife Trust" which has already bought and converted 84 ha of (lowly productive and sparsely populated) farmland to salt marshes (Myatt et al. 2003).

Table 7: *Summarized features of the preferential strategy for flood risk management in the three coastal regions of the Netherlands (according to Government of the Netherlands 2015).*

Region	Preferential Strategy	Flood risk management features
Southwest Delta	Room for innovative dikes	• The current dikes remain and will be improved • All dikes improvements will be investigated in order to make them multifunctional (i.e. possibilities for nature, recreation and living).
	Peak water storage and tides	• Investigation if peak water storage can be used to diminish the flood risk elsewhere. • If (limited) tides return, research will be necessary to investigate if the tides offer possibilities to combine ecologic recovery with sustainable energy (for example a tidal power station).
	Flood defence system, dikes, sand	• Adjusted management of storm surge barriers. • Bank and shoal nourishments to combat erosion. • Innovative (multifunctional) dike improvements.
	Dredging and dumping strategy	• Combination of innovative dikes with improved dredging and dumping strategies.
Holland Coast	A safe, attractive, economically robust coast	• Creating a sustainable coast with focus on safety, attractiveness and economic activities.
	Connecting flood risk management and spatial ambitions	• Connecting flood risk management, spatial development, nature conservation and recreation.
	Adaptive flood defence system, dikes and sand	• Design adaptive and sustainable protection measures
Wadden	Intertidal zone: adapt to rise in sea levels	• Preserve the buffer effect of the Wadden islands and the intertidal area as much as possible. • Annual replenishment of 12 million m3 sand.
	Primary flood defence systems: innovative and comprehensive	• Innovative dikes that create added values for nature, recreation and the regional economy.

Table 8: *Four generic options and accompanying sub-options of the TE2100 project to manage flood risk in the upcoming century (according to the EA 2012).*

Options	**Sub-options**	**Flood risk management features**
1. Improve the existing defences	1.1 Raise defences when needed 1.2 Allow future adaptation of defences 1.3 Optimise balance between defence, replacement and repair 1.4 Optimise defence repair and replacement, allow adaptation to future change	• The four different sub-options comprise different maintenance schedules and different decision paths of when and to what extend walls should be raised. • Until 2070, option 1.4 is the preferred option according to the TE2100 appraisal.
2. Tidal flood storage		• Storage of tidal waters could reduce extreme water levels at the Thames Barrier. • This option could 'buy time' to replace or improve the Thames Barrier (although it is not optimal).
3. New barrier	3.1 Tilbury location 3.2 Long Reach location	• Design of barriers to resist the highest predicted storm surge tides. • There would still be a need for defence upstream.
4. Barrier with locks	4.1 Tilbury location 4.2 Long Reach location 4.3 Barrier with locks at Thames Barrier (when closures per year reach their limit)	• Ship locks would allow vessels to pass through the barrier when it is closed. • The barrier with locks would be designed 'fail-safe' in order to close it as frequently as necessary without losing its reliability. • The most expensive option. • Most environmental damaging option.

3.5.b Increased awareness of society

According to the Floods Directive and ICZM, informing the population about flood risks and what to do in the event of flooding, is one of the key elements of an effective flood management approach.

To meet this requirement, the Netherlands included a "Multi-layer safety" approach in the Delta Programme: layer 1 represents the preventive measures to limit the probability of a flood, layer 2 represents the spatial organisation of an area to limit the consequences of any flood, and layer 3 represents the disaster and crisis management to respond effectively to any flood (Slomp 2012). In the United Kingdom, improved forecasting systems, improved spatial planning, effective preparation and emergency responses and help with recovery in case of disaster (the Flood Re contract) meet the requirement of the Floods Directive.

Both countries have made efforts to increase the awareness and preparedness of the public. In the Netherlands, risk communication campaigns as 'The Netherlands Lives with Water' and 'Think Ahead' were launched (Flood Aware 2013). Despite these efforts, there is still a large public awareness gap relating to flood risks (OECD 2014). To counteract this gap, the Dutch government has launched a new campaign in 2014: 'Will I flood?'. People can download the app or visit the website in order to access information on regional flood risks and emergency responses (Starflood 2015). In the United Kingdom, risk communication campaigns such as 'Know Your Flood Risk' and 'Co-FAST', as well as the 'National Flood Forum' and 'Risk and Regulation Advisory Council', have been more successful. Unlike the Netherlands, the United Kingdom instantly used an online marketing strategy to raise awareness. The use of various awareness strategies and techniques (TV, You-Tube, social media, personal e-mails) had more impact since they reinforced one another (Flood Aware 2013). Furthermore, since 2012 the EA has an online live flood warning system where people can consult local flood alerts and flood warning statuses (EA 2015b).

4. Conclusions and discussion

The results show that both countries aim to develop sustainable coastal management plans. The measures taken follow long-term integrated and participatory approaches and aim to balance environmental and socio-economic interests. The provided examples illustrate that progress is made in developing multi-functional, planning-based adaptive solutions to deal with pressures and impacts. Especially the combination of hard and soft coastal protection measures lead to innovative approaches (Tables 7 and 8). The responses to the effects of climate change of the Netherlands and the United Kingdom show a lot of similarities. Although the responses are not exactly the same, they are often based on a

similar underlying idea. Figure 5 represents the five major similarities between the responses of the two regions.

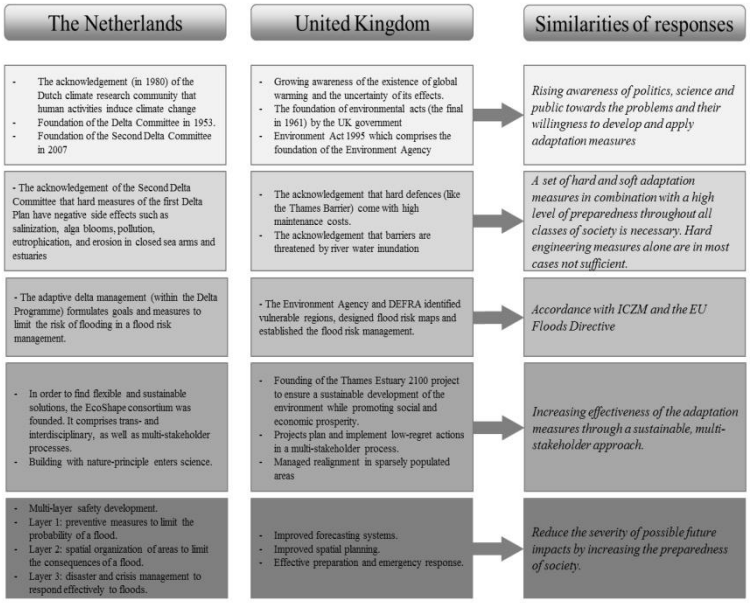

Figure 5: *Similarities between the responses of the Netherlands and the United Kingdom. The first two columns delineate a summary of responses, the third column represents the similarities between the responses of the two countries.*

Despite these similarities, the actual adaptation measures reveal some distinct differences. Firstly, the United Kingdom chooses hard defence measures in combination with managed realignment as the preferred adaptation method. In contrast to the Netherlands, where the paradigm is that no land should be lost, the United Kingdom has a more pragmatic approach. Where affordable, land, people, and property are defended by expensive but effective hard defence measures like the Thames Flood Barrier, while sparsely populated land might be given back to nature via structured realignment.

The second difference is an extension of the first one. The United Kingdom tries to combine a sustainable development with flood risk management but this is mainly the case in areas with low population density. The Netherlands, on the other hand, emphasizes sustainable development in all of its coastal regions. The EcoShape Consortium works on the boundaries between nature, engineering and society. Influenced by negative side effects of earlier-built hard measures, the Netherlands started to focus on flexible soft measures in harmony with the sea. However, there are cases where necessity is the mother of invention: in 2009, the province of Zeeland authorized the dumping of rubble and steel slag in order to make the dikes 'climate proof'. Yet the impact of the steel slag, containing heavy metals, on ecosystems was not taken into account when the slag deposit was authorized. Consequently, nature organizations have protested against steel slag deposits in the Oosterschelde (Stichting De Oosterschelde 2015).

A third major difference is in the options to manage flood risk in the future. In the Netherlands, the Building with Nature solutions are tailor-made and based on site-specific knowledge. After the termination of the projects, monitoring is crucial to operate and manage the Building with Nature -infrastructure, as there are no other generic options provided in the Netherlands (da Vriend et al. 2014). The United Kingdom, on the other hand, did provide

different generic options in the South East region. Due to the uncertainties of climate change, it chose to first monitor the development of climate change effects, population and property in order to choose the most credible adaptation option by 2050 (EA 2012).

The coastal areas of the Netherlands and the United Kingdom are vulnerable to the effects of climate change. Due to the rising temperature, induced by the human GHG emissions in combination with land use changes, the coastal areas have to deal with threats like sea-level rise, precipitation changes, increased frequency of severe storms, rising wave heights and growing river water discharge. Consequently, these threats induce an increased risk of floods, a deterioration of intertidal ecosystems, saline seepage, coastal squeeze, rising water tables and an impeded drainage which engender large economic impacts.

Lessons learned by the comparison of the two coastal regions are that the Netherlands and the United Kingdom followed the same path towards their current adaptation measures to combat the effects of climate change. First of all, there was a rising awareness in policy, science and society of the climate change problem. Consequently, the willingness to develop and apply adaptation and mitigation measures grew. Secondly, both countries acknowledged that hard measures alone are not sufficient. The Netherlands needed to cope with adverse effects (such as salinization, eutrophication, and erosion) due to the hard engineering measures. In the United Kingdom, the high maintenance costs of the hard measures and the threat of inundation by river water necessitated the supplementary use of soft measures. Thirdly, both countries needed to come up with a flood risk management in accordance with the Floods Directive (Directive 2007/60/EC). Fourthly, both countries abandoned the top-down approach and tried to increase the effectiveness of the adaptation measures through a sustainable, multi-stakeholder approach (ICZM). Finally, both countries have involved society and increased its preparedness regarding the possible effects of climate change.

Due to their geographical and geological differences, adaptation measures of the Netherlands and the United Kingdom are not overall the same. The United Kingdom differentiates between urban centres and sparsely settled rural areas: In urban areas with high population density and huge economic relevance, the method of choice is defence against flood risk by hard adaptation methods. For rural areas the importance as natural habitats, flood zones and recreation areas is stressed and hence managed realignment is the method of choice to ensure a sustainable development. As opposed to the approach of the United Kingdom, in the Netherlands the paradigm is that no land should be lost. Consequently, hard defence measures and sand replenishment in combination with more sustainable soft adaptation methods are

widely used. Hence, the Netherlands emphasizes a sustainable ecological, social and economic development in all its coastal regions.

Further research is necessary to show if the current adaptation measures are indeed sustainable, but this research can conclude that the current adaptation measures arose out of a transdisciplinary, sustainable way of thinking. Measures to counteract the effects of climate change and to secure sustainable development in coastal regions are currently based on a continuous, flexible process of multi-stakeholder collaboration, reflection and research. The development of sustainable coastal areas includes the use of existing hard protections measures in combination with new, nature-based soft adaptation measures.

Acknowledgements: This research was part of the European Virtual Seminar on Sustainable Development (www.ou.nl/evs). We thank all partners for sharing expertise and investing time and resources. We would like to thank Wilfried Ivens for his supervision and giving the opportunity to write this paper in the context of his course 'Scientific and Professional Publishing on Environment and Sustainability'.

References

Allen J.R.L. (2000), *Morphodynamics of Holocene salt marshes: a review sketch from the Atlantic and Southern North Sea coasts of Europe*, Quaternary Science Reviews, 19(12): 1155-1231. Doi: 10.1016/S0277-3791(99)00034-7.

Arnott S.A. and Ruxton G.D. (2002), *Sandeel recruitment in the North Sea: demographic, climatic and trophic effects*, Marine Ecology Progress Series, 238: 199-210. Doi: 10.3354/meps238199.

Atkins J.P., Burdon D., Elliot M., Gregory A.J. (2011), *Management of the marine environment: Integrating ecosystem services and social benefits with the DPSIR framework in a systems approach*, Marine Pollution Bulletin, 62(2): 215-226. Doi: 10.1016/j.marpolbul.2010.12.012.

Bingley R.M., Teferle F.N., Orliac E.J., Dodson A.H., Williams S.D., Blackman D.L., Baker T.F., Riedmann M., Haynes M., Press N., Aldiss D.T., Burke H.C., Chacksfield B.C., Tragheim D., Tarrant O., Tanner S., Reeder T., Lavery S., Meadowcroft I., Surendran S., Goudie J.R., Richardson D. (2008), *Measurement of current changes in land levels as input to long-term planning for flood risk management along the Thames estuary*, Journal of Flood Risk Management, 1(3): 162-172. Doi: 10.1111/j.1753-318X.2008.00018.x.

Borja A., Galparsoro I., Solaun O., Muxika I., Tello E.M., Uriarte A., Valencia V. (2006), *The European Water Framework Directive and the DPSIR, a methodological approach to assess the risk of failing to achieve good ecological status*, Estuarine, Coastal and Shelf Science, 66(1-2): 84-96. Doi: 10.1016/j.ecss.2005.07.021.

Brown J.D. and Damery S.L. (2002), *Managing flood risk in the UK: towards an integration of social and technical perspectives*, Transactions of the Institute of British Geograpers, 27(4): 412-426. Doi: 10.1111/1475-5661.00063.

Camanho A.S., Hora J., Gaspar M.B., Oliveira M.M. (2010), *Analysis of the artisanal fisheries in the Atlantic Arc based on the DPSIR framework*, FEUP/IPIMAR of Project PRESPO.

Carr E.R., Wingards P.M., Yorty S.C., Thompson M.C., Jensen N.K., Roberson J. (2007), *Applying DPSIR to sustainable development*, International Journal of Sustainable Development & World Ecology,

14(6): 543-555. Doi: 10.1080/13504500709469753.

Cave R.R., Ledoux L., Turner K., Jickells T., Andrews J.E., Davies, H. (2003), *The Humber catchment and its coastal area: from UK to European perspectives*, The Science of the Total Environment, 314-316: 31-52. Doi: 10.1016/S0048-9697(03)00093-7.

Daniels E.E., Lenderink G., Hutjes R.W.A., Holtslag A.A.M. (2014), *Spatial precipitation patterns and trends in the Netherlands during 1951-2009*, International Journal of Climatology, 34(6): 1773-1784. Doi: 10.1002/joc.3800.

Da Vriend H., van Koningsveld M., Aarninkhof S. (2014), *'Building with nature': the new Dutch approach to coastal and river work*, Proceedings of the Institution of Civil Engineers, 167(1): 18-24. Doi: 10.1680/cien.13.00003.

De Jong D.J., de Jong Z., Mulder J.P.M. (1994), *Changes in area, geomorphology and sediment nature of salt marshes in the oosterschelde estuary (SW Netherlands) due to tidal changes*, Hydrobiologia, 283(1): 303-316. Doi: 10.1007/BF00024638.

De Leeuw J., Methven J., Blackburn M. (2015), *Variability and trends in England and Wales precipitation*, International Journal of Climatology (online). Doi:10.1002/joc4521.

De Moel H., Aerts J.C.H., Koomen E. (2011), *Development of flood exposure in the Netherlands during the 20th and 21st century*, Global Environmental Change, 21(2): 620-627. Doi: 10.1016/1.gloenvcha.2010.12.005.

Deltacommissie (2008), *Samen werken met water. Een land leeft, bouwt aan zijn toekomst.* Zwolle, Hollandia Printing.

Deltawerken (2004), *De Deltawerken*. http://www.deltawerken.com/Deltawerken/16.html. (Accessed 08.01.2015)

Department of the Environment, Transport and the Regions (2000*), Climate Change. The UK Programme.* Norwich, Crown Copyright.

Dijkema K.S., van Duin W.E., Dijkman E.M., Nicolai A., Jongerius H., Keegstra H., van Egmond L., Venema H.J., Jongsma J.J. (2011), *Vijftig jaar monitoring en beheer van de Friese en Groninger kwelderwerken: 1960–2009.* Werkdocument 229. Wageningen, Wettelijke Onderzoekstaken Natuur & Milieu.

Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks.

EA - Environment Agency (2006), *Underground, under threat. The state of groundwater in England and Wales*. Bristol, Environmental Agency.

EA - Environment Agency (2012), *Managing flood risk through London and the Thames estuary. TE2100 Plan.* London, Thames Estuary 2100 Environment Agency.

EA - Environment Agency (2014), *The Thames Barrier*. https://www.gov.uk/guidance/the-thames-barrier. (Accessed 16.10.2015).

EA - Environment Agency (2015a), *Flood map for planning (from Rivers and the Sea)*. http://apps.environment-agency.gov.uk/wiyby/37837.aspx. (Accessed 16.02.2015).

EA - Environment Agency (2015b), *Flood warnings summary*. http://apps.environment-agency.gov.uk/flood/31618.aspx. (Accessed 16.10.2015).

EDGAR - Emissions Database for Global Atmospheric Research (2015), *GHG (CO2, CH4, N2O, F-gases) emission time series 1990-2012 per region/country.* European Commission, Joint Research Centre http://edgar.jrc.ec.europa.eu/overview.php?v=GHGts1990-2012. (Accessed 22.09.2015).

EEA - European Environment Agency (1999), *Environmental indicators: Typology and overview*. Technical report No. 25. Copenhagen, EEA.

EEA - European Environment Agency (2002), *An indicator-based approach to assessing the environmental performance of European marine fisheries and aquaculture*. Technical report No. 87. Copenhagen, EEA.

EEA - European Environment Agency (2010), *Tracking progress towards Kyoto and 2020 targets in Europe*. EEA Report No 7/2010. Copenhagen, EEA.

Elliot M. (2002), *The role of the DPSIR approach and conceptual models in marine environment management: an example for offshore wind power*, Marine Pollution Bulletin, 44(6): iii-vii. Doi: 10.1016/S0025-326X(02)00146-7.

Esteves L.S., Foord J., Walters G. (2014), 'Assessment of natural resources use for sustainable development - DPSIR framework for case studies in Portsmouth and Thames Gateway, U.K.' in Lan T.D., Olsson G.A., Alpokay, S. (eds) *Environmental stresses and resource use in coastal urban and peri-urban regions: DPSIR approach to SECOA's 17 case studies*. Rome, Sapienza Università Editrice, pp. 283-338. Doi: 10.13133/978-88-98533-23-7.

Eurosion (2004), *A guide to coastal erosion management practices in Europe: Lessons Learned*. The Hague, National Institute of Coastal and Marine Management of the Netherlands.

Eurostat (2015a), *Farmland: number of farms and areas by size of farm (UAA) and Nuts 2 regions.* http://ec.europa.eu/eurostat/web/products-datasets/-/ef_lu_ovcropaa. (Accessed 20.09.2015).

Eurostat (2015b), *Motorways network by NUTS 2 region*.

http://ec.europa.eu/eurostat/web/products-datasets/-/tgs00114. (Accessed 20.09.2015).

Eurostat (2015c), *Nights spent at tourist accommodation establishments by NUTS 2 region*s. http://ec.europa.eu/eurostat/web/products-datasets/-/tgs00111. (Accessed 20.09.2015).

Eurostat (2015d), *Population change – Demographic balance and crude rates at regional level (NUTS3).* http://ec.europa.eu/eurostat/en/web/products-datasets/-/DEMO_R_GIND3. . (Accessed 15.09.2015).

Eurostat (2015e), *Population density by NUTS 2 region.* http://ec.europa.eu/eurostat/tgm/table.do?tab=table&plugin=1&language=en&pcode=tgs00024. (Accessed 15.09.2015).

FAO - Food and Agriculture Organization (1999), *Indicators for sustainable development of marine capture fisheries*. FAO Technical Guidelines for Responsible Fisheries. No. 8. Rome, FAO.

Fischer G., Tubiello F.N., van Velthuizen H., Wilberg D.A. (2007), *Climate change impacts on irrigation water requirements: effects of mitigation, 1990-2080*. Technological Forecasting and Social Change, 74(7): 1083-1107.

Flood Aware (2013), *Raising flood awareness and self-efficacy. Framework to develop and implement a successful social marketing programme*. Middelburg, Flood Aware.

Foster N.M., Hudson M.D., Bray S., Nicholls R.J. (2013), *Intertidal mudflat and saltmarsh conservation and sustainable use in the UK: A review*, Journal of Environmental Management, 126: 96-104. Doi: 10.1016/j.jenvman.2013.04.015.

Frederiksen M., Edwards M., Roderick A.M., Wanless S. (2007), *Regional and annual variation in black-legged kittiwake breeding productivity is realted to sea surface temperature*, Marine Ecology Progress Series, 350: 137-143. Doi: 10.3354/meps07126.

French P. W. (2004), *The changing nature of, and approaches to, UK coastal management at the start of the twenty-first century*, The Geographical Journal, 170(2): 116–125. Doi: 0.1111/j.0016-7398.2004.00113.x

French, P. W. (2006), *Managed realignment–the developing story of a comparatively new approach to soft engineering*, Estuarine, Coastal and Shelf Science, 67(3): 409–423. Doi: 10.1016/j.ecss.2005.11.035.

Government of the Netherlands (2015), *Delta Programme 2015. Working on the delta – the decisions to keep the Netherlands safe and liveable.* The Hague, Ministry of Infrastructure and the Environment and the Ministry of Infrastructure and Economic Affairs.

Greater London Authrity (2005), *London under threat? Flooding risk in the Thames Gateway. Environment Committee.* London, Greater London Authority.

Hand W.H., Fox N.I., Collier C.G. (2004), *A study of twentieth-century extreme rainfall events in the United Kingdom with implications for forecasting*, Meteorological Applications, 11(1): 15-31. Doi: 10.1017/S1350482703001117.

Hopkins J.J., Allison H.M., Wamsley C.A., Gaywood M., Thurgate G. (2007), *Conserving biodiversity in a changing climate: guidance on building capacity to adopt.* London, Department for Environment, Food and Rural Affairs.

IACCF - Inter-Agency Climate Change Forum (2010), *Biodiversity and Climate Change in the UK*. Peterborough, Joint Nature Conservation Committee.

International Energy Agency (2015a), *Netherlands: Balances for 2012*. http://www.iea.org/statistics/statisticssearch/report/?country=NETHLAND&product=balances&year=2012. (Accessed 18.09.2015).

International Energy Agency (2015b), *United Kingdom: Balances for 2012*. http://www.iea.org/statistics/statisticssearch/report/?country=UK&product=balances&year=2012. (Accessed 18.09.2015).

IPCC - Intergovernmental Panel on Cimate Change (2014), *Climate Change 2014: Synthesis Report*. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. Geneva, IPCC.

Jenkins G.J., Perry M.C., Prior M.J. (2008), *The climate of the United Kingdom and recent trends*. Exeter(UK), Met Office Hadley Centre.

Jewell T. and Steele J. (1996), *UK Regulatory Reform and the Pursuit of Sustainable Development: The Environment Act 1995*, Journal of Environmental Law, 8(2): 283-300.

Jones C.G., Lawton J.H., Shachak M. (1994), 'Organisms as ecosystem engineers', in Samson F.B. and Knopf F.L. (eds) *Ecosystem Management – selected readings*, New York, Springer.

Jones P.D. and Conway D. (1997), *Precipitation in the British isles: an analysis of area-average data updated to 1995*, International Journal of Climatology, 17(4): 427-438. Doi: 0.1002/(SICI)1097-0088(19970330)17:4<427::AID-JOC139>3.0.CO;2-Q

Karageorgis A.P., Skourtos M.S., Kapsimalis V., Kontogianni A.D., Skoulikidis N.T., Pagou K., Nikolaidis N.P., Drakopoulou P., Zanou B.,Karamanos H., Levkov Z., Anagnostou Ch. (2005), *An integrated approach to watershed management within the DPSIR framework: Axios River catchment and Thermaikos Gulf*, Regional Environmental Change, 5(2): 138-160. Doi: 10.1007/s10113-004-0078-7.

Kennis voor Klimaat (2015), *Hotspots en onderzoeksthema's.* http://kennisvoorklimaat.klimaatonderzoeknederland.nl/onderzoeksprogramma/hotspots-en-themas. (Accessed 08.01.2015).

Klijn F., van Buuren M., van Rooij A.M. (2004), *Flood-risk management strategies for an uncertain future: Living with Rhine river floods in the Netherlands?*, AMBIO: A Journal of the Human Environment, 33(3):141-147. doi: http://dx.doi.org/10.1579/0044-7447-33.3.141

Knottnerus O.S. (2005), *History of human settlement, cultural change and interference with the marine environment*, Helgoland Marine Research, 59: 2-8. Doi: 10.1007/s10152-004-0201-7.

Lavery S. and Donovan B. (2005), *Flood risk management in the Thames Estuary looking ahead 100 years*, Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 363(1831): 1455-1474. Doi: 10.1098/rsta.2005.1579.

Lescrauwaet A.K., Vandepitte L., Vanden Berghe E., Mees J. (2006), *European sustainability indicators for coastal zones in The Netherlands: a first inventory*. VLIZ Special Publication 31. Oostende, Flanders Maine Institute and the SAIL partnership.

Linares P.B.C. (2012), *Sea level rise impacts on coastal zones: Soft measures to cope with it, Dalhousie Journal of Interdisciplinary Management, 8(2):* 1-16. Doi: 10.5931/djim.v8i2.282.

Lowe J., Howard T., Pardaens A., Tinker J., Holt J., Wakelin S., Milne G., Leake J., Wolf J., Horsburgh K., Reeder T., Jenkins G., Ridley J., Dye S., Bradley S. (2009), *UK climate projections science report: Marine and coastal projections*. Exeter(UK), Met Office Hadley Centre.

Lumbruso D.M. and Vinet F. (2011), *A comparison of the causes, effects and aftermaths of the coastal flooding of England in 1953 and France in 2010*, Natural Hazards and Earth System Sciences, 11(8): 2321-2333. Doi: 10.5194/nhess-11-2321-2011.

Ma Z., Ysebaert T., van der Wal D., de Jong D.J., Li X., Hermand P.M.J. (2014), *Long-term salt marsh vertical accretion in a tidal bay with reduced sediment supply*, Estuarine, Coastal and Shelf Science, 146: 14-23. Doi: 10.1016/j.ecss.2014.05.001.

Maraun D., Osborn T.J., Gillet N.P. (2008), *United Kingdom daily precipitation intensity: improved early data, error estimates and an update from 2000 to 2006*, International Journal of Climatology, 28(6): 833-842. Doi: 10.1002/joc.1672.

Marchand M. and Ludwig F. (2014), *Towards a comprehensive framework for adaptive delta management.* Wageningen, Delta Alliance.

Martins J.H., Camanho A.S., Gaspar M.B. (2012), *A review of the application of driving forces- pressure-state-impact-response framework for fisheries management*, Ocean & Coastal Management, 69: 273-281. Doi: 10.1016/j.ocecoaman.2012.07.029.

Ministry of Housing, Spatial Planning and the Environment (2006), *Initial report of The Netherlands for the calculation of its assigned amount under the Kyoto Protocol to the UNFCCC*. The Hague, VROM.

Mulder J.P.M., Hommes S., Horstman E.M. (2011), *Implementation of coastal erosion management in the Netherlands*, Ocean & Coastal Management, 54(12): 888-897. Doi: 10.1016/j.ocecoaman.2011.06.009.

Myatt L. B., Scrimshaw M. D., Lester J. N. (2003), *Public perceptions and attitudes towards an established managed realignment scheme: Orplands, Essex, UK*, Journal of Environmental Management, 68(2): 173-181. Doi: 10.1016/S0301-4797(03)00065-3.

Ness B., Anderberg S., Olsson L. (2010), *Structuring problems in sustainability science: The multi-level DPSIR framework*, Geoforum, 41(3): 479-488. Doi: 10.1016/j.geoforum.2009.12.005.

Nicholls R.J., Wong P.P., Burkett V.R., Codignotto J.O., Hay J.E., McLean R.F., Ragoonaden S., Woodroffe C.C. (2007), 'Coastal systems and low-lying areas', in Parry M.L., Canziani O.F., Palutikof J.P., van der Linden P.J., Hanson C.E. (eds), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, Cambridge University Press, pp. 315-356.

OECD (2014), *Water Governance in the Netherlands Fit for the Future?* Paris, OECD Publishing. Doi: 10.1787/9789264102637-en.

Osborn T.J., Hulme M., Jones P.D., Basnett T.A. (2000), *Observed trends in the daily intensity of United Kingdom precipitation*, International Journal of Climatology, 20(4): 347-364. Doi:

10.1002/(SICI)1097-0088(20000330)20:43.CO;2-C

Oude Essink G.H.P., Van Baaren E.S., De Louw P.G.(2010), *Effects of climate change on coastal groundwater systems: A modeling study in the Netherlands*, Water Resources Research (online), 46(10). Doi: 10.1029/2009WR008719.

Pauw P., de Louw P.G.B., Oude Essink G.H.P. (2014), *Groundwater salinization in the Wadden Sea area of the Netherlands: quantifying the effects of climate change, sea-level rise and anthropogenic interferences*, Netherlands Journal of Geosciences, 91(3): 373-383. Doi: 10.1017/S0016774600000500.

PBL Netherlands Environmental Assessment Agency (2013), *The effects of climate change in the Netherlands: 2012*. The Hague, PBL Netherlands Environmental Assessment Agency.

Pirrone N., Trombino G., Cinnirella S., Algieri A., Bendoricchio G., Palmeri L. (2005), *The Driver-Pressure-State-Impact_Response (DPSIR) approach for integrated catchment-coastal zone management: preliminary application to the Po catchment Adriatic Sea coastal zone system*, Regional Environmental Change, 5(2-3): 111-137. Doi: 10.1007/s10113-004-0092-9.

Pontee N. (2013), *Defining coastal squeeze: A discussion*, Ocean & Coastal Management, 84: 204-207. Doi: 10.1016/j.ocecoaman.2013.07.010.

Queffelec B., Cummins V., Bailly D. (2009), *Integrated management of marine biodiversity in Europe: Perspectives from ICZM and the evolving EU Maritime Policy framework*, Marine Policy, 33(6): 871-877. Doi: 10.1016/j.marpol.2009.04.016.

Recommendation (2002/413/EC) of the European parliament and of the Council of 30 May 2002 concerning the implementation of Integrated Coastal Zone Management in Europe (2002/413/EC).

Ritzema H.P. and Stuyt L.C.P.M. (2015), *Land drainage strategies to cope with climate change in the Netherlands*, Acta Agriculturae Scandinavica, Section B – Soil & Plant Science, 65(sup1): 80-92. Doi: 10.1080/09064710.2014.994557.

Safecoast (2008), *Coastal flood risk and trends for the future in the North Sea region, synthesis report*. The Hague, Safecoast project team.

Salman A., Lombardo S., Doody J.P. (2004), *Living with coastal erosion in Europe: Sediment and space for Sustainability. PART 1 – Major findings and policy recommendations of the EUROVISION project*. Brussels, European Commission.

Slomp R. (2012), *Flood risk and water management in the Netherlands*. Delft, Rijkswaterstaat, Ministry of Infrastructure and the Environment.

Sorensen J. (1993), *The international proliferation of integrated coastal zone management efforts*, Ocean & Coastal Management, 21(1): 45-80. Doi: 10.1016/0964-5691(93)90020-Y.

Starflood (2015), *Awareness raising: a crucial element in Dutch flood risk management*. http://www.starflood.eu/column/awareness-raising-a-crucial-element-in-dutch-flood-risk-management/. (Accessed 12.10.2015).

Stichting De Oosterschelde (2015), *Raad van State: 'Rijkswaterstaat heeft ten onrechte staalslakken gestort' En nu?* http://www.stichtingdeoosterschelde.nl. (Accessed 30.09.2015).

Stojanovic T. I. M. and Barker N. (2008), *Improving governance through local Coastal Partnerships in the UK*, Geographical Journal, 174(4): 344–360. Doi: 10.1111/j.1475-4959.2008.00303.x.

Taal M., Mulder J., Cleveringa J., Dunsbergen D. (2006), *15 years of coastal management in the Netherlands; Policy, implementation and knowledge framework.* The Hague, Rijkswaterstaat, National Institute for Coastal and Marine Management/RIKZ.

Titus J.G., Kuo C.Y., Gibbs M.J., LaRoche T.B., Webb M.K., Waddell J.O. (1987), *Greenhouse effect, sea level rise, and coastal drainage systems*, Journal of Water Resources Planning

and Management, 113(2): 216-225. Doi: 10.1061/(ASCE)0733-9496(1987)113:2(216).

Turner R. K., Burgess D., Hadley,D., Coombes E., Jackson N. (2007), *A cost–benefit appraisal of coastal managed realignment policy*, Global Environmental Change, 17(3): 397–407. Doi: 10.1016/j.gloenvcha.2007.05.006.

Tyndall Centre (2015), *Tyndall Centre for Climate Research*. http://www.tyndall.ac.uk/about. (Accessed 30.10.2015).

Van der Wal D. and Pye K. (2004), *Patterns, rates and possible causes of saltmarsh erosion in the Greater Thames area (UK)*, Geomorphology, 61(3): 373-391. Doi: 10.1016/j.geomorph.2004.02.005.

Van Keeken O.A., van Hope M., Rijnsdorp A.D. (2007), *Changes in the special distribution of North Sea plaice (Pleuronectes platessa) and implications for fisheries management*, Journal of Sea Research, 57(2-3): 187-197. Doi: 10.1016/j.seares.2006.09.002.

Van Overloop P.-J. (2006), *Drainage control in water management of polders in the Netherlands*, Irrigation and Drainage Systems, 20(1): 99-109. Doi: 10.100è/s10795-006-5424-0.

Van Wesenbeeck B.K., Mulder J.P.M., Marchand M., Reed D.J., de Vries M.B., de Vriend H.J., Herman P.M.J. (2014), *Damming deltas: A practice of the past? Towards nature-based flood defences*, Estuarine, Coastal Shelf Science, 140: 1-6. Doi: 10.1016/j.ecss.2013.12.031.

Verduijn S.H., Meijerink S.V., Leroy P. (2012), *How the Second Delta Committee Set the agenda for climate adaptation policy: A Dutch case study on framing strategies for policy change*, Water Alternatives, 5(2): 469-484.

Wamsley J.J. (2002), *Framework for measuring sustainable development in catchment systems*, Environmental Management, 29(2): 195-206. Doi: 10.1007/s00267-001-0020-4.

Waterman R.E. (2010), *Integrated coastal policy via building with nature.* Doctoral dissertation. Delft, Delft University of Technology.

Weijerman M., Lindeboom H., Zuur, A.F. (2005), *Regime shifts in marine ecosystems of the North Sea and Wadden Sea*, Marine Ecology Progress Series, 298: 21-39.

World Bank (2015a), *Fossil fuel energy consumption (% of total).* http://data.worldbank.org/indicator/EG.USE.COMM.FO.ZS/countries. (Accessed 15.09.2015).

World Bank (2015b), *Population density.* http://data.worldbank.org/indicator/EN.POP.DNST?page=2. (Accessed 15.09.2015).

About the Aegean Journal of Environmental Sciences (AEJES)

The **Aegean Journal of Environmental Sciences** (AEJES) is an open-access, free of charge e-journal published by the Department of Environment, University of the Aegean, Greece. AEJES publishes peer reviewed, original research on the study of the natural environment and on the society-nature interactions. Although AEJES prime aim is to provide a forum for postgraduate (M.Sc. and Ph.D.) students on environmental sciences programs to publish their research it also strongly welcomes contributions from established scholars and researchers in the field.

Research Areas include, but are not exclusive to:

- Environmental Politics, Policy and Sociology
- Environmental Economics and Management
- Environmental Education
- Environmental Pollution and Restoration
- Biodiversity and Conservation
- Global Environmental Change
- Environmental Health and Toxicology

For further information, please visit the journal's website:
http://www.env.aegean.gr/aejes/