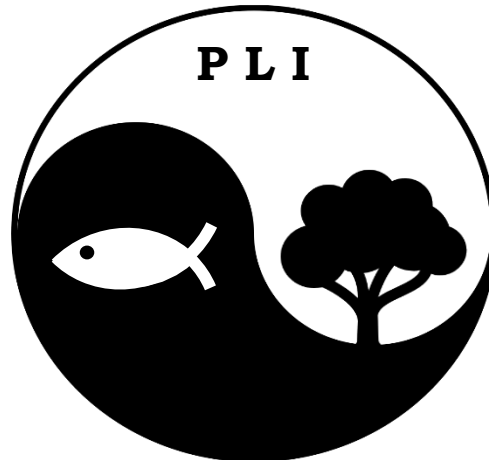# Developing a Protection Level Index (PLI) for Protected Areas

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Abstract

The number of designated Protected Areas (PAs) worldwide has been increasing fast over the past decades and currently 15.1% of the land and 7.9% of the ocean's surface are under protection. However, the mere designation of a PA does not guarantee any degree of protection. Where the IUCN Categorizing system classifies PAs solely based on the management strategy on paper, the actual effects of this management remain undetermined. Over the past years, thousands of PA effectiveness methodologies have been developed and applied to PAs from all over the world. However, the majority of the existing assessments are not entirely fit for a quick and easy assessment of the actual quality of the protection in place. Therefore, we propose a new method that assesses the effects of the PA management and thereby reflects the actual degree of protection within the borders of a PA. We present the Protection Level Index (PLI), an index (ranging from 0 to 1) that is based on the scores for 12 equally weighted managerial, socio-economic and ecological sub-indices that are based on both the results from a questionnaire and an analysis of the spatial characteristics of the PA in a GIS. One of the great advantages of PLI is that it omits pre-defining universal optimal conditions and instead allows the PA manager(s) to put numerical quantifications into context. PLI has been tested for 7 European PAs covering a wide range of environmental regimes. The results indicate that some the sub-indices are closely related to each other and that despite the dissimilarities between the 7 PAs, they all have a similar final PLI score in the midrange around 0.63. This emphasizes the unbiased character of PLI, which makes it an ideal protected area management effectiveness method that can be applied to any PA worldwide.

Contents

Appendix A – PLI questionnaire
Appendix B – Borders of the 7 Protected Areas used in this study

1. Introduction

It has been common practice for centuries to protect areas in order to conserve the ecologic and economic values they contain. For the first Protected Areas (Pas) the conservation intentions were mainly to safeguard hunting grounds and maintaining wildlife stocks. However, with time the focus shifted towards preventing irreversible damage and loss of natural habitats and species as a result of intensified human activities. Still, a large range of conservation goals exist and every Protected Area (PA) has its own motives for its designation. The unique character of PAs and their management makes it difficult to set forth a single definition for a PA. In order to include as many types of PAs as possible, Article 2 of the Convention of the Biological Diversity (adopted June 1992) serves as the PA definition for this study: a "protected area" means a geographically defined area which is designated or regulated and managed to achieve specific conservation objectives.

As more and more PAs were established in one country after the other and each nation had its own management approach and standards, the IUCN started an effort to clarify terminology and develop an international categorizing system for PAs in 1933. In 1994 the IUCN defined six (management) categories that classify PAs according to their management objectives: Ia – Strict nature reserve, Ib – Wilderness area, II – National park, III – Natural Monument or feature, IV – Habitat/species management area, V – Protected landscape or seascape and VI – Protected areas with sustainable use of natural resources. However, the mere establishment of a PA and designating an IUCN Category to it, does not guarantee its success. With the IUCN Category being solely based on the management strategy and not on the actual effects in the field of that strategy, so called "paper parks", PAs that have little or no formal management on the ground, can occur (Brandon *et al*., 1998 and Bonham *et al*., 2008). Even though many efforts have been made to develop protected area management effectiveness methodologies (Blanco and Gabaldon, 1992; Courrau, 1999; Dudley *et al.*, 1999; Hockings *et al.*, 2000; Cifuentes *et al.*, 2000; Ervin, 2003a; Blom *et al.*, 2004; BirdLife International, 2006; Stolton *et al.*, 2007 and Marthur, 2008), the majority of these methods are often not globally-applicable (Hockings & Phillips, 1999). In addition, assessment methods are often too focussed on the regulations in place and not on whether these regulations produce the desired results in the field (Pomeroy, 2004).

This study presents a new measure that allows for a quick and easy assessment of the actual degree of protection in any type of PA worldwide. The Protection Level Index (PLI) that we propose here considers a set of 12 managerial, socio-economic and ecological sub-indices and combines them into one final PLI score. One of the innovative elements of PLI is that it uses the perception of the PA manager(s) to put numerical quantifications of (some of) the parameters into context. The scores for 7 of PLI sub-indices are based on the results from PLI questionnaire (Appendix A) and the other 5 are based on the results from an analysis in a Geographical Information System (GIS) on the spatial characteristics of the PA. The individual scores for the sub-indices should offer the PA managers a quick insight into which aspects of the PA do or do not need improvement.

PLI has been tested in 7 European PAs that were selected from the PAs that participated in the EcoPotential project. The selected PAs are a diverse set of PA types, from both a managerial and an ecological point of view, and cover a wide range of environmental regimes, such as lakes, lagoons, dunes, wetlands, forests, caldera's and mountains. The first PA is located in North-Macedonia and is named "Lake Prespa Monument of Nature" (IUCN Category III) and is largely covered by the freshwater Lake Prespa. The second PA is named "Pieniny National Park" (IUCN Category II) lies in Slovakia adjacent to the border with Poland and consists of the eastern part of the Pieniny mountain range. The third PA is the "Danube Delta Biosphere Reserve" (IUCN Category II), an alluvial plain consisting of wetlands and marshes located in Romania where the Danube River flows into the Black Sea. The fourth PA is the "Island Network of Protected Areas" on the volcanic island of La Palma consists of 19 sub-PAs, each with their own IUCN Category ranging from I-V. The fifth PA is the "Curonian Spit National Park" (IUCN Category II) that covers the 93 km long Lithuanian part of a sand-dune spit that lies parallel to the west coast of Lithuania and Russia. The sixth PA are the mountain forests in the "Bavarian Forest National Park" (IUCN Category II) in Germany with bog lakes and meadows. The seventh and final PA used for testing PLI methodology is the "Kalkalpen National Park" (IUCN Category II) located in the Northern Limestone Alps mountain range in Austria.

2. Methods

The Protection Level Index (PLI) score of a PA is based on 12 socio-economic and environmental sub-indices that are derived from essential variables identified in previous interviews of PA managers in the context of EcoPotential (Hummel *et al.*, 2018). The sub-indices for PLI have been selected in such a way that they allow for a quick and easy assessment of the degree of protection in a PA. All computations for PLI sub-indices are designed in such a way that a maximum score of 1 is obtained in the case of a desirable situation (high level of protection) and a minimum score of 0 in case of an undesirable situation (low level of protection).

A total of 7 PAs have been visited in the period 2018-2019, during which PLI-questionnaire was conducted within ~1.5 hours. Processing the spatial data (in a GIS) of a single PA takes about 3-6 hours depending on the quality, number and resolution of the shapefiles provided by the PA management.

2.1 PLI sub-indices based on the results of PLI-questionnaire

The scores of one set of PLI sub-indices are computed on the basis of the results from PLI-questionnaire (Appendix A). PLI-questionnaire presents a set of questions for a single sub-index, commonly the first question requests a numerical quantification of the status quo, followed by the manager's perception on that matter. In this way objective data is placed into context by using the (subjective) evaluation of the PA manager. This approach allows PLI to be applicable to a wide variety of PAs, because the unique character of PAs makes it unjustifiable to assess matters purely on numerical quantifications.

2.1.1 *Illegal Activity Regulations*

The Illegal Activities Regulations sub-index is based on the presence of a set of activities listed in Table 1, that are viewed as detrimental to the protection of areas (derived from the illegal activities listed in the study by Hummel *et al.* (2018)). The PA managers were asked to indicate for each activity on the list whether it is regarded as a legal or illegal activity in the PA. In case an activity is regarded as legal that activity has been disregarded. When an activity is regarded illegal, the extent to which that activity takes place in the PA determines the score assigned to that activity (Table 2).

1. Agriculture/Aquaculture
2. Commercial extraction of wild biological resources
3. Non-commercial extraction of biological resources
4. Building infrastructure
5. Recreation
6. Poaching
7. Extraction of non-renewable natural resources
8. Drone flights
9. Motorized access
10. Littering
11. Vandalism

Table 1. List of activities used in Illegal Activity Regulations sub-index of PLI.

Extent to which this illegal activity takes place in the PA	A_k
Does not take place	1.00
Takes place to a *negligible* extent	0.80
Takes place to a *small* extent	0.60
Takes place to a *moderate* extent	0.40
Takes place to a *large* extend	0.20
Takes place to a *very large* extent	0.00

Table 2. The individual score, A_k, assigned to an illegal activity from the list in Table 1 is determined by the extent to which that activity takes place in the PA.

The extent to which an illegal activity takes place, reflects the ability of the management to control illegal activities in the PA and thus ensure protection of its nature. In the ideal situation, the management can control and prevent the occurrence of an illegal activity, which is rewarded with the maximum score of 1. The Illegal Activity Regulations sub-index, I_i, reflects the score (sum of the individual scores, A_k) as a fraction of the maximum score:

$$I_i = \frac{1}{n} \sum_{k=1}^{n} A_k$$

where n presents both the number of activities regarded as illegal and the maximum possible score, and A_k is the individual score of kth illegal activity (Table 2).

2.1.2 Enforcement Employees

The Enforcement Employees sub-index is based on the number of enforcement employees that work in/for the PA. An enforcement employee is defined as a person that is authorized to arrest and/or enforce a penalty on an offender of the rules of the PA. There is no method currently available that computes/predicts the optimal enforcement employee density (Plumptre *et al.*, 2014)). This is due to that fact that it strongly depends on factors such as the size and location of the PA, the type of threat faced, the human population density and the animal species that require protection. Studies of African PAs have shown that a ranger density of 1 ranger per 10-50 km^2 appears to be adequate to control poaching activities (Henson *et al.*, 2016; Vreugdenhil, 2003 and Lindsey *et al.*, 2011). Taking this value into account we defined 5 categories for the enforcement employee density and linked a score to those densities (Table 3).

Category	Enforcement density (km^2 per enforcement employee)	E_1
I	1 – 12.5 km^2	0.20
II	12.5 – 25 km^2	0.30
III	26 – 50 km^2	0.40
IV	51 – 100 km^2	0.20
V	$\geq$ 101 km^2	0.00

Table 3. The individual score, E_1, assigned to the enforcement employees density of the PA.

The final score for the Enforcement Employees sub-index is a combination of the numerical quantification of the number of enforcement employees (40%) and the perception of the manager on this number (60%). In the desirable situation, the number of enforcement employees is, according to the PA manager, "adequate", which corresponds to a (maximum) score of 0.60 (Table 4). Naturally, a lack of employees remains worse than a superfluous amount of employees, therefore the score lowers with -0.30 with respect to "adequate" in case of shortage. However, the score

also lowers (with steps of -0.10 with respect to "adequate") in case of "superfluous", because this means that financial resources (i.e. salaries) are wasted on aspects that do not directly increase the quality of the PA.

PA managers perception on the number of enforcement employees	E_2
The number of enforcement employees is *way too low* in order to ensure well-functioning of the PA	0.00
The number of enforcement employees is *slightly too low* in order to ensure well-functioning of the PA	0.30
The number of enforcement employees is *adequate* in order to ensure well-functioning of the PA	0.60
The number of enforcement employees is *slightly too high* in order to ensure well-functioning of the PA	0.50
The number of enforcement employees is *way more than needed* in order to ensure well-functioning of the PA	0.40

Table 4. The individual score, E_1, assigned to the perception of the PA manager on the enforcement employees density.

The Enforcement Employees sub-index, I_e, is calculated as follows:

$$I_e = E_1 + E_2$$

See Table 3 and 4 for E_1 and E_2 respectively.

2.1.3 Controlled Visitor Behaviour

Humans are not by default detrimental for PAs, when managers can keep control over the behaviour of them, an effective balance between nature and humans can exists from which the PA can benefit (Parolo *et al.*, 2009). The more the PA manger can control the behaviour of its visitors, the more likely the PA manager is able to prevent these visitors from disturbing the nature in the PA (Marion & Reid, 2007). This is captured in the Controlled Visitor Behaviour sub-index of PLI, which consists of three aspects:
1. the way in which visitors can enter/exit the PA,
2. the presence of pathways (for terrestrial PAs) and/or shipping lanes (for aquatic PAs)
3. the percentage of pathways/shipping lanes that are clearly indicated

A PA that is fully fenced with only a limited number of entrances provides a high degree of controlling the behaviour of visitors. However, such a hard boundary significantly lowers the connectivity. Therefore, the highest score (0.50) for the way in which visitors can enter/exit the PA, is assigned to a PA that is not fully enclosed with a fence, but where visitors are concentrated by using designated entrances (Table 5).

How can the PA be accessed?	V_1
The PA is fully fenced and can only be accessed via a limited number of entrances	0.25
The PA has no fence and can be accessed anywhere along the border	0.00
The PA has no fence, but we concentrate visitors by using designated entrances (e.g. parking lots, public transport connections, visitor centres, harbours)	0.50

Table 5. The individual score, V_1, assigned to the way in which visitors and enter/exit the PA.

The presence of pathways and/or shipping lanes increases the control on the behaviour of visitors and thus results in a maximum score of 0.25, where its absence results in a score of 0.00 (Table 6).

Presence of pathways/shipping lanes?	V_2
Pathways/shipping lanes are not present	0.00
Pathways/shipping lanes are present	0.25

Table 6. The individual score, V_2, assigned to the presence or absence of pathways/shipping lanes.

Even when pathways and/or shipping lanes are present, visitors are more likely to use them when such pathways are part of a hike/route that is clearly indicated with directional signs. Therefore, the higher the percentage of pathways and/or shipping lanes that are part of such a route, the more likely that visitors will use these pathways/shipping lanes and thus the higher the control of the manager on the behaviour of the visitors. Table 7 gives the score assigned to these percentages.

Percentage of the pathways/shipping lanes that is part of specified routes indicated with directional signs	V_3
0%	0.00
1% - 20%	0.05
21% - 40%	0.10
41% - 60%	0.15
61% - 80%	0.20
81% - 100%	0.25

Table 7. The individual score, V_2, assigned to the percentage of the pathways/shipping lanes that is part of specified routes that are clearly indicated with directional signs.

The Controlled Visitor Behaviour sub-index, I_{cvb}, is a sum of the individual scores of the three abovementioned aspects:

(1)

$$I_{cvb} = V_1 + V_2 + V_3$$

See Table 5, 6 and 7 for V_1, V_2 and V_3 respectively.

2.1.4   Funding

The amount of funding a PA receives has a major influence on the capacity of the PA manager to regulate proper management and ensure a high degree of (nature) protection. Two aspects must be considered when assessing the yearly PA funding: the surface area of the PA and the economic health of the country. Therefore, we corrected the PA funding value as follows:

$$F_1 = \frac{\left(\frac{F_{PA}}{A_{PA}}\right)}{GNI}$$

where F_{PA} is the (average) funding that the PA receives on a yearly basis (in €), A_{PA} is the total surface area of the PA (in km^2) and GNI is the Gross National Income per capita (in €) of the country in which the PA is located. In this way F_1 represents the fraction of the GNI per capita that is available for 1 km^2 of the PA. For example, a F_1 value of 0.30 means that the funding that is available for each square kilometre in the PA is equal to 30% of the GNI per capita. As all sub-indices have a range from 0-1, an upper limit is created, by assuming that a F_1 value of 0.50 is sufficiently high (if $F_1 > 0.50$, then $F_1 = 0.50$). As every PA is unique, this numerical approach of the funding is not the only determinant of the Funding sub-index, the remaining 0.50 is determined by the perception of the PA manager on the amount of funding (F_2) (Table 8).

Perception of the manager on the amount of park funding	F_2
Absolutely insufficient, critical lack of funding	0.10
Partly insufficient, the PA management can go on but there is still a big lack of funding	0.20
Sufficient, all (required) management actions can be executed	0.30
More than sufficient, enough funding for proper management and some additional actions	0.40
Superfluous, more than enough funding for management and many additional actions	0.50

Table 8. The individual score, F_2, assigned to the perception of the PA manger on the amount of funding that the PA receives.

The Funding sub-index, I_f, is calculated as follows:

$$I_f = F_1 + F_2$$

See equation (1) for F_1 and Table 8 for F_2.

2.1.5 Corruption Regulations

The Corruption Regulations sub-index is calculated by using a classification system which combines the country's Corruption Perception Index (CPI) with the perception of the PA manager on whether the country's CPI is representative for the level of corruption in the PA itself. The CPI is published each year by the Transparency International organization and offers a snapshot of the relative degree of corruption of countries and territories from all over the globe. The CPI ranges from 0 (the highest level of perceived corruption) to 100 (the lowest level of perceived corruption) and Table 9 shows the class assessment based on the CPI value.

CPI value	Class
1 – 10	1
11 – 20	2
21 – 30	3
31 – 40	4
41 – 50	5
51 – 60	6
61 – 70	7
71 – 80	8
81 – 90	9
91 – 100	10

Table 9. Class assessment based on the CPI value of the country in which the PA is located.

The perception of the manager on the level of corruption in the PA can change this class to a final class: if the current level of corruption in the PA is viewed as much higher than, slightly higher than, correctly, slightly lower than or much lower than indicated by the country's CPI, the class changes by –2, –1, 0, +1 or +2 respectively (Figure 1). In this classification system the maximum class is always 10 and the minimum class is always 1, even after the class changes.

CPI

	0	10	20	30	40	50	60	70	80	90	100

Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10
$I_c = 0.1$	$I_c = 0.2$	$I_c = 0.3$	$I_c = 0.4$	$I_c = 0.5$	$I_c = 0.6$	$I_c = 0.7$	$I_c = 0.8$	$I_c = 0.9$	$I_c = 1.0$

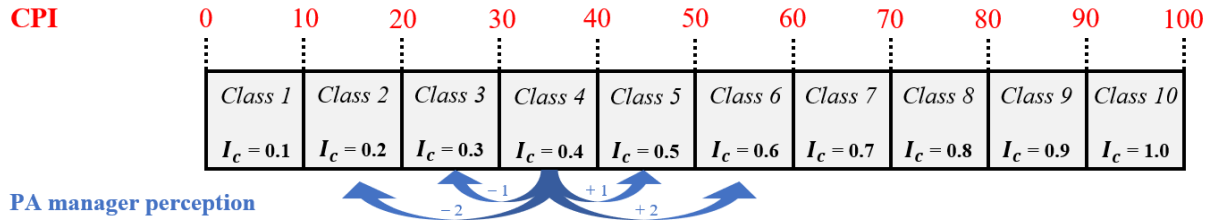**PA manager perception**   −1 +1 −2 +2

Figure 1. Example showing how to determine the Corruption Regulations index using a Classification system in which the country's CPI determines the Class (e.g. a CPI value of 31-40 falls in Class 4) and depending on the perception of the PA manager on the level of corruption in the PA, the Class can change with a maximum of 2.

The Corruption Regulations sub-index, I_c, is calculated as follows:

$$I_c = \frac{C_{final}}{10}$$

where C_{final} is the final class (1-10) after the class change due to the perception of the PA manager (Fig. 1).

2.1.6 🦋 Biodiversity

The biodiversity of a PA strongly depends on the type of ecosystem, e.g. tropical rainforests have much higher species densities than deserts. Therefore, in order to allow PLI to be applicable to any type of PA, the Biodiversity sub-index is not designed to quantify and evaluate biodiversity, but rather to assess the effort put in by managers to monitor and safeguard the biodiversity in their PA.

The Biodiversity sub-index, I_b, is then calculated as follows:

$$I_b = \frac{B_1 + (B_2 * k) + B_3 + B_4}{4}$$

In which the value of the B terms depend on the answers of the following questions:
1. Is the biodiversity measured in one way or another?   ($B_1 = 1$ if yes, $B_1 = 0$ if no)
2. Is historical reference data available?   ($B_2 = 1$ if yes, $B_2 = 0$ if no)
3. Are there invasive species present?   ($B_3 = 0$ if yes, $B_3 = 1$ if no)
4. What is the impact of invasive species?   ($B_4 = 1$ if +, $B_4 = 0$ if – and $B_4 = 0.5$ if neutral)

The B_2 term is multiplied by k $(0 – 1)$, which is the average fraction of how many species are present today compared to about 50 years ago. Since k is an average, the exact number of species monitored does not matter.

2.1.7 🎯 *Management Objectives*

For the Management Objectives sub-index, a list of 12 management objectives that are essential for the protection of a PA, has been established. To each of these objectives a score of 1 is assigned when this objective is included in the management plan of the PA and a score of 0 upon its absence. If there is no management plan present, but the manager indicates that he does manage by that objective, a lower score of 0.50 is assigned. This is because the PA manager cannot be abided to achieving these management objectives when they are not officially recorded in a written management plan. In the desirable situation a management plan is present and all the 12 management objectives listed in Table 10 are included and a maximum score of 12 can be obtained.

Management objective	Management plan present		Management plan <u>not</u> present	
	Included	*Not included*	*Managed by*	*Not managed by*
	score	**score**	**score**	**score**
Protection of endangered species	1.00	0.00	0.50	0.00
Protection of a nationally significant landscape	1.00	0.00	0.50	0.00
Protection of ecosystem services	1.00	0.00	0.50	0.00
Protection of cultural sites	1.00	0.00	0.50	0.00
Protection of natural resources for sustainable use	1.00	0.00	0.50	0.00
Providing food or other products for the markets/Provide benefits to the local and national economy	1.00	0.00	0.50	0.00
Maintaining natural processes	1.00	0.00	0.50	0.00
Preserve significant natural features	1.00	0.00	0.50	0.00
Safeguard the genetic diversity	1.00	0.00	0.50	0.00
Provide recreation and tourism services	1.00	0.00	0.50	0.00
Provide education, research and environmental monitoring	1.00	0.00	0.50	0.00
Provide homes to human communities with traditional cultures and knowledge of nature	1.00	0.00	0.50	0.00

Table 10. The 12 management objectives that are essential for the protection of a PA converted into a score based on whether these objectives are included in the management plan and in case a management plan is absent, whether the PA is managed by these objectives.

The Management Objectives sub-index, I_m, represents the fraction of the maximum score that is obtained and is calculated as follows:

$$I_m = \frac{m_{present}}{12}$$

in which $m_{present}$ is the sum of the 12 individual scores (Table 10).

2.2 PLI sub-indices based on the spatial characteristics of the PA (GIS data)

The remaining set of PLI sub-indices are based on the spatial characteristics of the PA and can be computed in a Geographical Information System (GIS). Shapefiles regarding the border outline of the PA, the roads, the settlements and agricultural lands/aquaculture are required for the computation of the following PLI sub-indices.

2.2.1 Edge Effects

The perimeter of a PA forms the contact zone between protected and unprotected area. It is assumed that the longer the contact zone, the higher the chance that the protected area is negatively influenced by the neighbouring unprotected area (Woodroffe & Ginsberg, 1998; Ries & Sisk, 2004 and Balme *et al.*, 2010). Also, the longer the PA border, the more effort must be put in controlling (illegal) in- and outflows across the border. Therefore, the desirable situation is a PA with a PA border perimeter as short as possible. The shortest possible perimeter for a given PA surface area is the perimeter of a circle with the same surface area. The Edge Effects sub-index, I_{ee}, represents the ideal perimeter as a fraction of the actual perimeter of the PA:

$$I_{ee} = \frac{P_{ideal}}{P_{PA}} = \frac{2\pi\sqrt{\frac{A_{PA}}{\pi}}}{P_{PA}}$$

where A_{PA} is the total surface area of the PA (in m^2) and P_{PA} is the perimeter of the PA (in m).

2.2.2 Naturalness

Commonly, the rationale behind the designation of a PA is to minimize the (negative) impacts that humans can have on nature. Therefore, it is assumed that the more anthropogenic structures in a PA, the higher the degree of disturbance and thus the lower the degree of nature protection. The Naturalness sub-index reflects the fraction of anthropogenic structures in the PA compared to natural structures. The anthropogenic structures included in this sub-index are:

- settlements (including industrial areas, quarries, dumps)
- agricultural lands or aquaculture
- roads (dirt roads are excluded)

The surface area of an anthropogenic structure is calculated in ArcMAP (using shapefiles supplied by the PA mangers or by manually drawing polygons based on satellite images). In case of roads, not only the road itself is considered as an unnatural structure, but also the area directly adjacent to the road (e.g. the maintenance of the vegetation, signs of milestones, lanterns etc.). Therefore, a buffer zone is added on both sides of the road. The width of this buffer zone depends on the type of road. Table 11 shows the three types of roads used in this study.

Road type	Total width of road	Number of lanes	Degree of through traffic	Width buffer zone
Primary roads	> 20 m	≥ 2 lanes	High (high ways)	15 m
Secondary roads	10 - 20 m	2 lanes	Medium	10 m
Tertiary roads	< 10 m	1 lane	Low (local roads)	5 m

Table 11. Division of asphalt roads into three categories, local roads smaller than 10 meters, roads with a medium degree of through traffic that are between 10 and 20 meters wide and roads (e.g. highways) with a high degree of through traffic that are wider than 20 meters. Emergency lanes are regarded as a lane and are a common feature of primary roads.

All primary roads are regarded as 4 lane roads, assuming a lane width of 4 meters, the anthropogenic surface area covered by primary roads equals the total length of the primary roads (in m) multiplied by 46 m. Same for secondary roads, from which the length is multiplied with 28 m and for tertiary roads the length is multiplied by 14 m (Figure 2).

The Naturalness sub-index, I_n, represents the surface area of non-anthropogenic structures as a fraction of the total PA area:

$$I_n = \frac{A_{PA} - A_{antrop}}{A_{PA}}$$

where A_{PA} is the total surface area of the PA (in m^2) and A_{antrop} is the total surface area of the anthropogenic structures inside the border of the PA (in m^2).
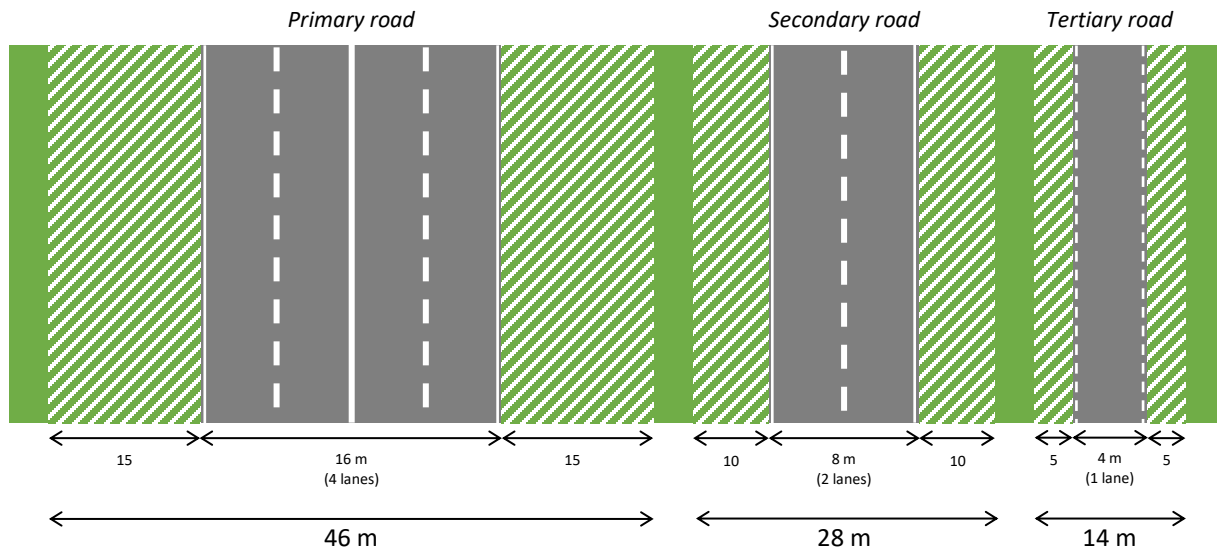

Figure 2. Schematic drawing of primary, secondary and tertiary roads together with the widths of their corresponding buffer zones.

2.2.3　　Light Pollution

For billions of years, life has evolved with Earth's predictable rhythm of light and dark controlled by the length of the day. In fact, many plants and animals depend on this daily light-dark cycle to govern life-sustaining behaviour such as reproduction, nourishment, sleep. Artificial lights in the night originating from human settlements, (can) disrupt the natural behaviour of plants and animals and is therefore regarded as a negative impact on the degree of protection in a PA (Aschoff, 1960; Longcore & Rich, 2004 and Chepesiuk, 2009).

The Light Pollution sub-index assesses the artificial light intensities that occur in the PA, for which the online light pollution map (www.lightpollutionmap.info) produced by the Light Pollution Science and Technology Institute (ISTIL) (Falchi *et al.*, 2016) has been used. This map reports simulated zenith radiance from artificial light (natural light sources are not included). The light pollution map uses a colour range on a zenith sky brightness scale that ranges from 22.0 magnitude/arcsecond^2 (low light intensity) to 17.5 magnitude/arcsecond^2 (high light intensity). This scale has been divided into three categories: I, II and III (Table 12).

Category			Zenith sky brightness scale (magnitude/arcsecond^2)		
I	Low	light intensity	22.0	to	21.7
II	Medium	light intensity	21.7	to	20.6
III	High	light intensity	20.6	to	17.5

Table 12. Division of the zenith sky brightness scale from the pollution map into three categories.

The Light Pollution sub-index is based on the fractions of the surface area of the PA that fall in category I, II and III. This is estimated by manually drawing polygons on the light pollution map that mark areas with colour ranges corresponding to the three categories. For each category the total surface area that falls in that category is expressed as a fraction of the total surface area of the PA.

The Light Pollution sub-index, I_l, is calculated as follows:

$$I_l = 1 - \left[\left(\frac{A_I}{A_{PA}} \cdot 0 \right) + \left(\frac{A_{II}}{A_{PA}} \cdot 0.5 \right) + \left(\frac{A_{III}}{A_{PA}} \cdot 1 \right) \right]$$

where A_{PA} is the total surface area of the PA (in m^2) and A_I, A_{II} and A_{III} are the surface areas (in m^2) that fall in category I, II and III respectively.

2.2.4 Fragmentation

Roads cross cutting a PA divide the area in fragments and thereby lower the connectivity (Bruschi *et al.*, 2001). Fragmentation has a negative impact on the flow of genes, as isolation reduces the flow of genes between subpopulations and hence the genetic differentiation increases and the genetic diversity decreases (Corlatti *et al.*, 2009). The Fragmentation sub-index assesses the degree of fragmentation caused by the presence of primary and secondary roads (Figure 2) (assuming that tertiary roads can be crossed by animals relatively easy).

The Fragmentation sub-index does not only take the number of fragments into account, but also the surface area of these fragments. This is done because a PA with one large fragment and a few smaller fragments provides a larger surface area of undisturbed habitat compared to a PA with the same number of fragments, but where all fragments have a moderate size. In the desirable situation the PA is one large fragment and the surface area of the largest fragments equals the total surface area of the PA.

The Fragmentation sub-index, I_f, is calculated as follows:

$$I_{frag} = \frac{1}{f} \cdot \frac{A_{largest\ frag}}{A_{PA}}$$

where f is the number of fragments, $A_{largest\ frag}$ is the surface area of the largest fragment in the PA (in m^2) and A_{PA} is the total surface area of the PA (in m^2).

2.2.5   Expandability

      The degree of protection generally increases towards the centre of a PA, this is because the outer rim of the PA is closer to unprotected areas and therefore experiences higher distortions by humans (Woodroffe & Ginsberg, 1998; Balme *et al.*, 2010; Ries & Sisk, 2004). Therefore, the larger the PA, the larger the central area that experiences a high degree of protection. Accordingly, a PA manager should always explore its possibilities to expand the PA.

      The Expandability sub-index reflects the potential of a PA to expand perpendicular to its borders, in order to include additional adjacent areas that are currently not under protection. To this extend, an expansion band has been drawn along the PA border. In order to take the size of PA's into account, the width of this expansion band is ought to be 20% of the radius of an ideal circle that has the same surface area as the PA:

$$W_{band} = 0.2\ *\ \sqrt{\frac{A_{PA}}{\pi}}$$

where A_{PA} is the total surface area of the PA (in m^2). In case the PA consists of multiply PA segments, A_{PA} equals the sum of the surface areas from the individual segments. No matter the size of the segments, all segments obtain an expansion band with the same width. When segments are near to each other such that their expansion bands overlap, the bands are merged.

The part of the expansion band that falls under different management authorities or beyond national jurisdiction (neighbouring countries) are excluded from the total surface area of the expansion band. The surface areas covered by anthropogenic structures (settlements) in the expansion band obstruct the expansion of the PA and are therefore subtracted from the total surface area of the expansion band. In the desirable situation, anthropogenic structures are absent in the expansion band and the Expandability sub-index has a maximum score of 1.

The Expandability sub-index, I_{exp}, is calculated as follows:

$$I_{exp} = \frac{A_{exp\ band} - A_{antropogenic\ in\ exp}}{A_{exp\ band}}$$

where $A_{exp\ band}$ is the total surface area of the expansion band (in m^2) and $A_{antropogenic\ in\ exp}$ is the total surface area of the anthropogenic structures that fall in the expansion band (in m^2).

2.3 Studied Protected Areas

A total of 7 European PAs (Table 13) participated in the development of PLI methodology. The wide range of environmental regimes that are covered by these 7 PAs enabled the development of the universal character of PLI.

Protected Area official name	Country	Year of foundation	IUCN Category	Environmental regime
Lake Prespa Monument of Nature	North-Macedonia	1995	III	Lake
Pieniny National Park	Slovak Republic	1967	II	Mountainous/forest
Danube Delta Biosphere Reserve	Romania	1991	II	River delta
Island Network of Protected Areas – La Palma	Spain	1994	I-VI	Island
Curonian Spit National Park	Lithuania	1991	II	Beach/Dunes
Bavarian Forest National Park	Germany	1970	II	Mountainous/forest
Kalkalpen National Park	Austria	1997	II	Mountainous/forest

Table 13. The 7 Protected Areas used in this study.

2.3.1 Lake Prespa Monument of Nature

Lake Prespa Monument of Nature (Appendix B.1) is a PA located in the south of North-Macedonia. It is established in 1995 and designated as an IUCN Category III PA. The border of the PA coincides with the boundaries of the municipality of Resen (16,825 inhabitants in 2002). Apart from the town Resen (9000 inhabitants in 2002) many other smaller villages are located in the PA. The PA has total surface area of 784 km^2, from which 176 km^2 is taken up by the North-Macedonian part of Lake Prespa, which is shared with Albania and Greece in the south. Lake Prespa lies at 849 m above sea level, has a total surface area of 254 km^2, a catchment area of about 1300 km^2, a maximum water depth of 48 m and a mean water depth of 14 m. The total inflow of water is estimated to be 16.9 m^3/s, with 56% originating from river runoff, 35% from direct precipitation and 9% from the smaller Lake Mikri Prespa in the south. Lake Prespa loses its water through evaporation (52%), irrigation (2%) and outflow through underground karst aquifers (46%) to the ~150 m lower lying Lake Ohrid in the west.

2.3.2 Pieniny National Park (Slovakia)

Pieniny National Park (Appendix B.2) is a PA located in northern Slovakia. It is established in 1967 and designated as an IUCN Category II PA. The PA is located in the Slovak districts of Kežmarok and Stará Ľubovňa in the Prešov Region and only contains the village Lesnica (504 inhabitants in 2013). Pieniny National Park has a total surface area of 37 km^2 and includes the Slovak part of the transboundary Pieniny mountain range, which is shared with Poland. Tourist attractions in Pieniny National Park are the hiking routes and the wooden raft trips through the Dunajec River Gorge, which is the border river between Poland and Slovakia. The Pieniny Mountains in Poland are also protected, however under the management of another PA called Pieniny National Park (Poland). This study only examined the (management of the) Pieniny National Park PA in Slovakia.

2.3.3 Danube Delta Biosphere Reserve

The Danube Delta Biosphere Reserve (Appendix B.3) is a PA located in the east of Romania, where the Danube River flows in the Black Sea. It is established in 1991 and designated as an IUCN Category II PA. The Danube Delta Biosphere Reserve PA has a total surface area of 5,838 km^2 which covers the Romanian part of the Danube Delta, the Ukrainian part in the north is excluded. Inside the PA live about 20,000 people, from which about 4,600 in the port of Sulina in the east and the rest is scattered among 27 smaller villages. The Danube Delta is a low alluvial

plain with an average altitude of about 0.50 m. It is mostly covered by wetlands and water and is characterized by reed beds, marshes, channels, streamlets and lakes. This mixture of aquatic and terrestrial environments is situated on major bird migratory routes and provide the perfect conditions for nesting and hatching. From the 375 bird species in Romania, 320 live in the Danube Delta Biosphere Reserve or migrate to it in summer or winter (Gâştescu, 2009). At the western edge of the Danube Delta, just outside the borders of the PA, lies the city of Tulcea (73,707 inhabitants in 2011).

2.3.4 Island Network of Protected Areas – La Palma

The Island Network of Protected Areas (Appendix B.4) is located on La Palma, the most north-westerly Canary Island (Spain). This PA Network consists of 19 "sub-PAs", with IUCN Categories ranging from I to V. The total surface area of the PA Network is 249 km^2. La Palma has 81,863 inhabitants (2018), from which 15,674 live in the capital Santa Cruz de la Palma and about 20,000 in Los Llanos de Aridane. Unlike the other Canary Islands La Palma has is stead of mass tourism, ecotourism. About 200,00 tourists visit La Palma each year, mainly because of the many hiking trails. The sub-PAs are dispersed over the entire island where some of them are directly adjacent to each other and others are isolated patches. Sub-PAs that share boundaries have been merged into one (larger) sub-PA. The majority of the sub-PAs only contains small (parts of) villages, whereas the sub-PAs in the middle of the island are uninhabited. The Caldera de Taburiente National Park (P-0) lies in the middle of the island and contains the Caldera de Taburiente, it was already designated as a National Park in 1954. The Roque de los Muchachos (2426 m), the highest point on the island, is located on the northern wall of the caldera and close to this summit is the Roque de los Muchachos (astronomical) Observatory located. The other sub-PAs cover a wide range of environmental regimes from forests to volcanic ridges to beaches.

2.3.5 Curonian Spit National Park

The Curonian Spit (Appendix B.5) is a 93 km long sand-dune spit that lies parallel to the west coast of Lithuania and Russia. It is established in 1991 and designated as an IUCN Category II PA. The spit separates the Curonian lagoon in the east from the Baltic Sea in the west. The Curonian Spit National Park PA comprises the northern 52 km of the Curonian Spit that belongs to Lithuania. It has a surface area of 272 km^2 and a maximum width of 3,8 km. From south to north runs one main road that passes by the following settlements: the resort town Nida (~ 2,385 inhabitants in 2012), the village of Preila, Pervalka, Juodkrantė, Alksnynė and Smiltynė. In the north-east of the Curonian Spit, nearby Smiltynė, the Smiltynė Ferry forms a (transport) connection between the spit and the city of Klaipėda on the main land of Lithuania. The Curonian Spit PA consists of beaches, dunes, wetlands, meadows and forests and is a popular holiday destination for about 200,000 to 300,000 tourists each summer, mostly Lithuanians, Germans, Latvians, and Russians.

2.3.6 Bavarian Forest National Park

The Bavarian Forest National Park (Appendix B.6) PA is located in Germany in the Eastern Bavarian Forest adjacent to the border with the Czech Republic. It was established in 1970 and designated as an IUCN Category II PA. The PA has a surface area of 242 km^2 and its border have been drawn in such a way that most villages have been omitted/excluded, which created gaps. The Bavarian Forest National Park PA mainly consists of low and high mountain forests, but also includes some bog lakes and meadows. The PA offers visitors a large network of signposted trails, long-distance hikes, adventure trails and wooden boardwalks. In the Bavarian Forest live amongst others, lynxes, wildcats, beavers, otters, bats, red deer, moose and in 2016 a pair of wolves were discovered. However, since visitors

often don't encounter these animals in the wild, a zoo (Tier-Freigelände) has been established in the south of the PA, where visitors can spot the native mammal and bird species.

2.3.7 Kalkalpen National Park

The Kalkalpen National Park (Appendix B.7) is located in the state of Upper Austria, Austria. It is established in 1997 and designated as an IUCN Category II PA. The border of the PA has been defined in such a way that towns, villages and main traffic roads in the area have been excluded, creating gaps and fragments. The Kalkalpen National Park PA has a total surface area of 208 km^2 from which about 80% is covered by pines, spruces and beeches. The PA is located within the Northern Limestone Alps mountain range and contains Europe's largest forested area, as well as the largest karst region in Austria. Apart from forests, rivers, canyons, waterfalls and lakes can be found in the Kalkalpen PA. The park is home to about 50 species of mammals, among which the rare and endangered lynx, about 80 species of breeding birds, about 1000 species of flowering plants, moss and ferns and 1400 species of butterflies. The Kalkalpen National Park PA attracts tourists and offers in its visitors centre in the town of Molln an exhibition on the nature of the Kalkalpen, information on guided tours, maps of the extensive network of hiking/biking trails and other activities. In winter there are alpine skiing routes in the west of the PA.

3. Results

The scores for PLI sub-indices are, as described in the Methods section, derived from the scores assigned to the answers from the questionnaires and scores computed based on the analyses of the spatial data in GIS. Table 14 lists for each PA their scores for the 12 PLI sub-indices and the final PLI score, which is the average of the 12 scores for PLI sub-indices. The Biodiversity sub-index could not be computed for the Curonian Spit, Bavarian Forest and Kalkalpen National Parks, because an older version of PLI-questionnaire that did not include equivalent questions regarding the biodiversity in the PA, has been used. Therefore, the final PLI score for these three PAs is based on the scores of the remaining 11 PLI sub-indices.

	Lake Prespa Monument of Nature	Pieniny National Park	Danube Delta Biosphere Reserve	Island Network of Protected Areas - La Palma	Curonian Spit National Park	Bavarian Forest National Park	Kalkalpen National Park
Illegal Activity Regulations	0.90	0.73	0.57	0.60	0.62	0.70	0.76
Enforcement Employees	0.60	0.30	0.00	0.30	0.30	0.80	0.60
Controlled Visitor Behaviour	0.45	1.00	0.75	0.50	0.50	1.00	1.00
Funding	0.37	0.57	0.37	0.26	0.27	1.00	0.95
Corruption Regulations	0.60	0.50	0.50	0.40	0.70	0.80	1.00
Biodiversity	0.63	0.62	0.50	0.49	-	-	-
Management Objectives	0.25	0.25	0.83	0.92	0.58	0.75	0.83
Edge Effects	0.70	0.49	0.36	0.16	0.51	0.26	0.28
Naturalness	0.85	0.88	0.86	0.96	0.98	0.99	0.97
Light Pollution	0.86	1.00	0.98	0.98	0.74	1.00	1.00
Fragmentation	0.04	0.49	1.00	0.01	0.12	0.24	0.03
Expandability	1.00	0.95	0.99	0.96	0.92	0.59	0.92
Final PLI score	**0.60**	**0.65**	**0.64**	**0.55**	**0.57**	**0.74**	**0.76**

Table 14. Scores for PLI sub-indices and the final PLI score for the 7 PAs that participated in this study. The final PLI score is the average of the 12 individual scores for PLI sub-indices. The Biodiversity sub-index could not be computed for the Curonian Spit, Bavarian Forest and Kalkalpen National Parks, because the managers of these three PAs had been interviewed with an older version of PLI-questionnaire that did not include equivalent questions regarding the biodiversity in the PA. Therefore, the final PLI score for these three PAs is based on the scores of only 11 PLI sub-indices.

3.1 Lake Prespa Monument of Nature

Lake Prespa has high scores regarding the control on illegal activities and the potential to expand the PA. In addition, the absence of large cities is reflected in a high score for the Light Pollution index. Despite the presence of agricultural lands and villages, Lake Prespa scores relatively high on the Naturalness index, which can (partly) be explained by the fact that the lake itself takes up a large fraction of the surface area of the PA. Traffic roads in this PA divide the area in 7 fragments, from which the largest fragment is only 31% of the total surface area, this results in a low score for the Fragmentation index. Lake Prespa has a relatively low score for the Management Objectives index, this is because their management plan only contains 3 out of the 12 pre-defined management objectives for which PLI tests. The remaining indices have a midrange score (Figure 3). The average of PLI sub-indices, gives a final PLI score of **0.60** for the Lake Prespa Monument of Nature.
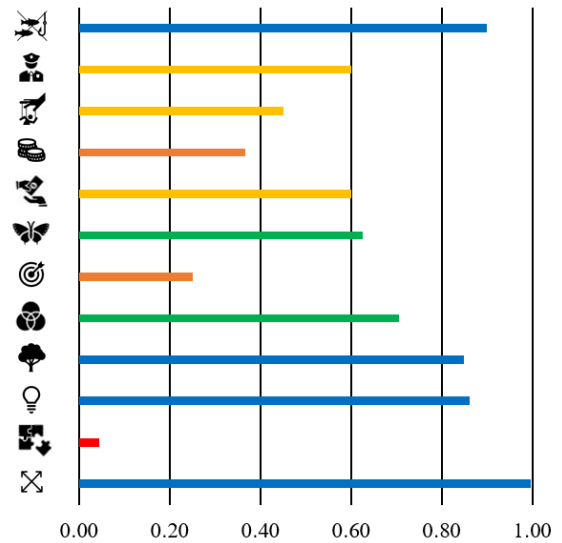
Figure 3. Scores for PLI sub-indices for the Lake Prespa Monument of Nature.

3.2 Pieniny National Park (Slovakia)

The presence of designated entrances and indicated hiking paths in Pieniny yields a high degree of control over the movements of visitors within the PA, resulting in a maximum score of 1 for the Controlled Visitor Behaviour index. Also, its remote location and the absence of large cities make that 100% of the PA's surface area falls into the lowest light pollution category (I), giving a maximum score for the Light Pollution index as well. The low amount of anthropogenic structures both in and directly adjacent to the PA cause a relatively high score for both the Naturalness and Expandability index. Also, the Illegal Activities Regulations index shows a high score, due to the fact that the activities regarded as illegal only take place only to a negligible to small extend. On the other hand, the management of Pieniny National Park emphasizes a critical lack of enforcement employees (rangers) as their two current rangers each have to cover 18 km^2 this results in a relatively low score for the Enforcement Employees index. The Management Objectives index has the lowest score in Pieniny, because even though they manage by 7 out of the 12 pre-defined management objectives, this is not endorsed by an actual management plan. The remaining indices have a midrange score (Figure 4). The average of PLI sub-indices, gives a final PLI score of **0.65** for the Pieniny National Park.
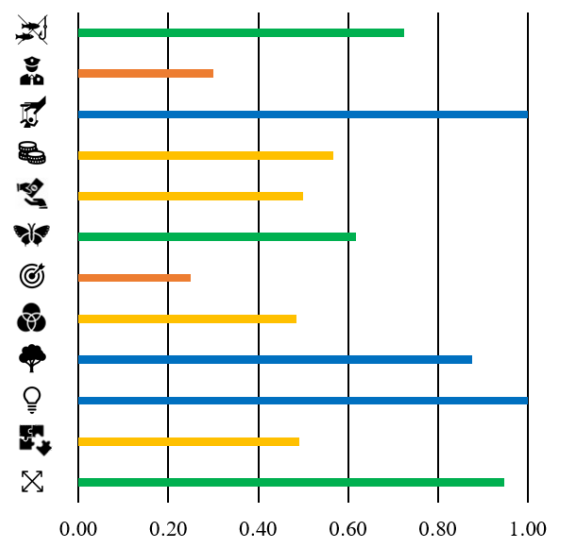
Figure 4. Scores for PLI sub-indices for the Pieniny National Park (Slovakia).

3.3 Danube Delta Biosphere Reserve

The Danube Delta has a maximum score of 1 for the Fragmentation index, due to the fact that the roads do not divide the PA in fragments. Apart from a small fraction in the west (close to the city of Tulcea), the majority of the surface area falls into the lowest light pollution category (I), giving a very high score for the Light Pollution index. The high potential for expansion is reflected in the score for the Expandability index. The wetlands, marshes and lakes make the Danube Delta quite unsuitable for human settlements, explaining the relatively high score for the Naturalness index. The high score for the Management Objectives index is the result of their management plan including 11 out of the 12 pre-defined management objectives that PLI tests for. For the Enforcement Employees index, the Danube Delta has the lowest possible score. The 14 enforcement employees each have to cover an area of 414 km^2 and the management indicates that this is insufficient to ensure well-functioning of the management. The relatively low score for the Edge Effects index (partly) results from the geometry of the PA in the west, where it runs parallel on both side of the Danube river, which significantly adds to the length of the PA perimeter, but does not comprise a large area. The remaining indices have a midrange score (Figure 5). The average of PLI sub-indices, gives a final PLI score of **0.64** for the Danube Delta Biosphere Reserve.
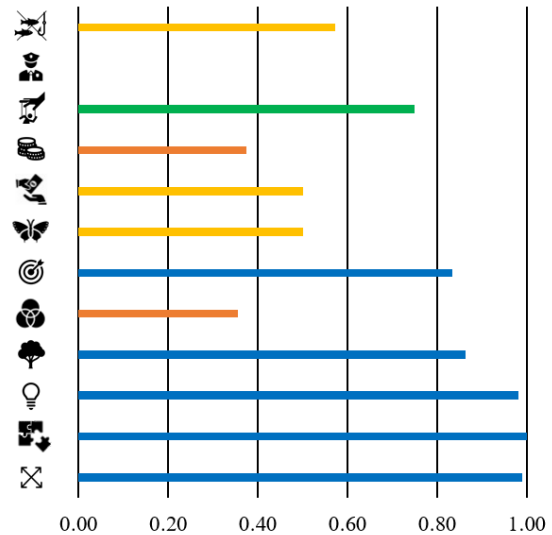

Figure 5. Scores for PLI sub-indices for the Danube Delta Biosphere Reserve.

3.4 Island Network of Protected Areas – La Palma

La Palma is known for the astronomical observatory and takes measures in order to reduce light pollution, explaining the very high score for the Light Pollution index. The PA border has been drawn in such a way that the PA consists of several "patches" of smaller PAs, gives an unavoidable low score for the Fragmentation index and for the Edge Effects index. However, a longer PA border offers more opportunities to expand and ideally to connect the patches of PA. This in combination with the low population density of La Palma results in a high score for the Expandability index. Also, the score for Management Objectives index is very high. However, a critical lack of funding prevents the execution of the objectives and gives a low score for the Funding index. The remaining indices have a midrange score (Figure 6). The average of PLI sub-indices, gives a final PLI score of **0.55** for the Island Network of Protected Areas – La Palma.
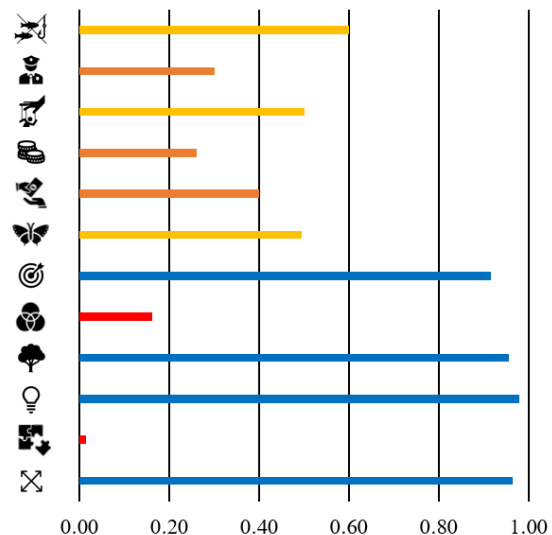

Figure 6. Scores for PLI sub-indices for the Island Network of Protected Areas – La Palma.

3.5 Curonian Spit National Park

The sparsely populated dunes of the Curonian Spit result in high scores for the Naturalness, Expandability and Light Pollution indices. A CPI value of 59 for Lithuania (2017) combined with the manager indicating that the level of corruption inside the PA is slightly less than indicated by this CPI value, gives a relatively high score on the Corruption Regulations index. The relatively low value for the Fragmentation index is due to the fact that the main traffic road runs along the north-south axis of the spit, which more or less splits the PA in half. As the Fragmentation index is inversely proportional to the surface area of the largest fragment, splitting the PA in half results in a relatively low score for the Fragmentation index. The lowest scores have been obtained for the Enforcement Employees and Funding indices. The remaining indices have a midrange score (Figure 7). The average of PLI sub-indices, gives a final PLI score of **0.57** for the Curonian Spit National Park.
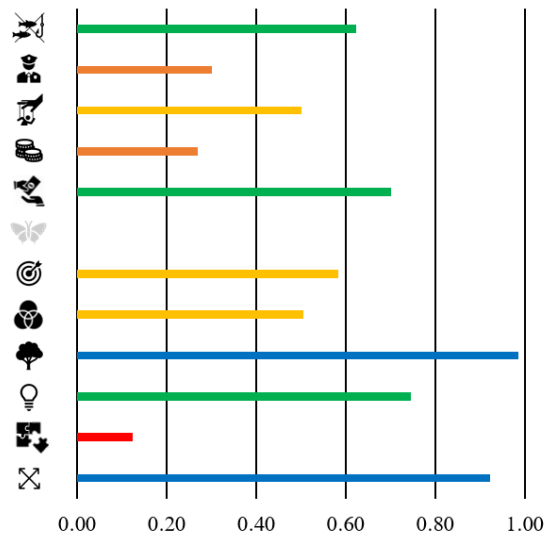

Figure 7. Scores for PLI sub-indices for the Curonian Spit National Park. Note that the Biodiversity index could not be computed.

3.6 Bavarian Forest National Park

The Bavarian Forest has the maximum score for the Controlled Visitor Behaviour index, the Funding index, the Light Pollution index and a score of 0.99 for the Naturalness index. This PA receives sufficient funding to implement an appropriate set of measures, such as hiking trails, which facilitate and guide the visitors through the PA. The high score for the Naturalness index is due to the very low population density of this mountainous area in combination with the fact that the villages present in the area have been excluded from the PA by drawing the PA borders around them. This created a few gaps in the PA and three fragments of smaller PAs close to the border of the largest fragment (Appendix B.6). The largest fragment of the Bavarian Forest covers about 99% of the total PA surface and in combination with 4 fragments, this results in a relatively low score for the Fragmentation index. The tortuous outline of the PA border causes a relatively low score for the Edge Effects index as well. The Bavarian Forest also scores quite high on the Illegal Activity Regulations, Enforcement Employees, Corruption and Management Objectives indices. Only for the Expandability index this PA has a midrange score (Figure 8). The average of PLI sub-indices, gives a final PLI score of **0.74** for the Bavarian Forest National Park.
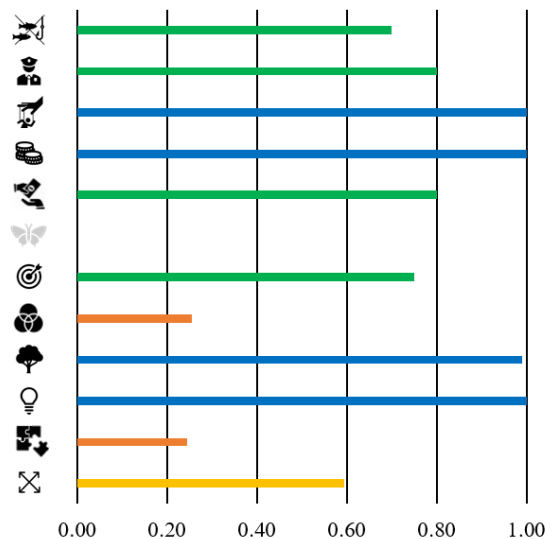

Figure 8. Scores for PLI sub-indices for the Bavarian Forest National Park. Note that the Biodiversity index could not be computed.

3.7 Kalkalpen National Park

The Kalkalpen National Park has the maximum score for the Controlled Visitor Behaviour index because it has designated entrances and all of the paths are part of a route. The maximum score is also achieved for the Corruption Regulations index, due to the combination of a relatively high CPI value and the manager indicating that the actual corruption in the PA is much lower than indicated by the CPI. The remote location of this mountainous PA causes that 100% of the PA falls in the lowest light pollution category and therefore scores a maximum of 1 on the Light Pollution index. High scores are also obtained for the Funding index, the Naturalness index, the Expandability index and the Management Objectives index. The high score regarding the funding is due to the fact that Kalkalpen National Park receives more than €28,000 per km^2 per year and the managers indicate that this is sufficient. Whereas the high score for the Naturalness index is rather due to the fact that the PA border has been drawn in such a way that villages and main traffic roads have been omitted. This goes at the expense of the score for the Fragmentation index, because the PA consists of 35 fragments. The high number of fragments also increases the total perimeter of the PA border, which gives a relatively low score for the Edge Effects index. (Figure 9). The average of PLI sub-indices, gives a final PLI score of **0.76** for the Kalkalpen National Park.
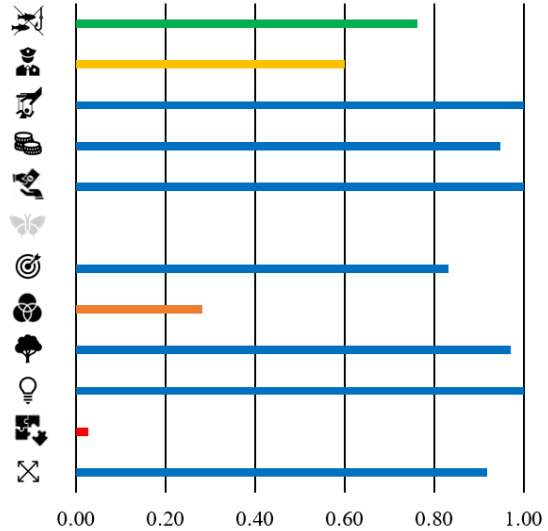

Figure 9. Scores for PLI sub-indices for the Kalkalpen National Park. Note that the Biodiversity index could not be computed.

3.8 Comparing PLI (sub-indices) scores between the 7 PAs

For some PLI sub-indices, such as the Illegal Activity Regulations index, the Biodiversity index, the Naturalness index, the Light Pollution index and the Expandability index the 7 PAs show very similar scores (Figure 10). Whereas the scores for the other PLI sub-indices show a great variability between the 7 PAs. For example, the scores for the Enforcement Employees index range from 0.00 for the Danube Delta to 0.80 for the Bavarian Forest and for the Fragmentation index, scores range from 0.04 for La Palma to 1.00 for the Danube Delta.

Despite the variation in the scores for the sub-indices, all 7 PAs have similar final PLI scores. The lowest final PLI score is 0.55 and belongs to the Island Network of Protected Areas in La Palma and the highest final PLI score equals 0.76 and belongs to the Kalkalpen National Park.

3.9 Correlations between scores for PLI sub-indices within one PA

The scores for the GIS-based PLI sub-indices (Edge Effects, Naturalness, Light Pollution, Fragmentation and Expandability) are independent of each other. This is because these indices each assess a different spatial characteristic of the PA and these characteristics are unrelated to each other. On the contrary, the other PLI sub-indices assess aspects of the PA that are related to each other. For example, the number of (enforcement) employees is in reality often related to the amount of funding. As a result, scores for the Enforcement Employees index and the Funding index might show

a correlation. In order to test this, a linear regression analysis has been performed on different sets of PLI sub-indices (Figure 11).

The results of the linear regression analysis revealed that the score for the Funding index does not (directly) explain the variance in the scores for the Illegal Activities Regulations index ($R^2 = 0.0872$), but it does explain about 49% of the variability observed in the scores for the Enforcement Employees index and about 72% of the variance in the scores for the Controlled Visitors Behaviour index. The score for the Enforcement Employee index explains about 42% of both the variance in the scores for the Illegal Activities and Corruption Regulations indices. Finally, the scores for the Corruption Regulations index do not show a correlation with the scores for the Illegal Activities Regulations index ($R^2 = 0.1098$) (Figure 11).
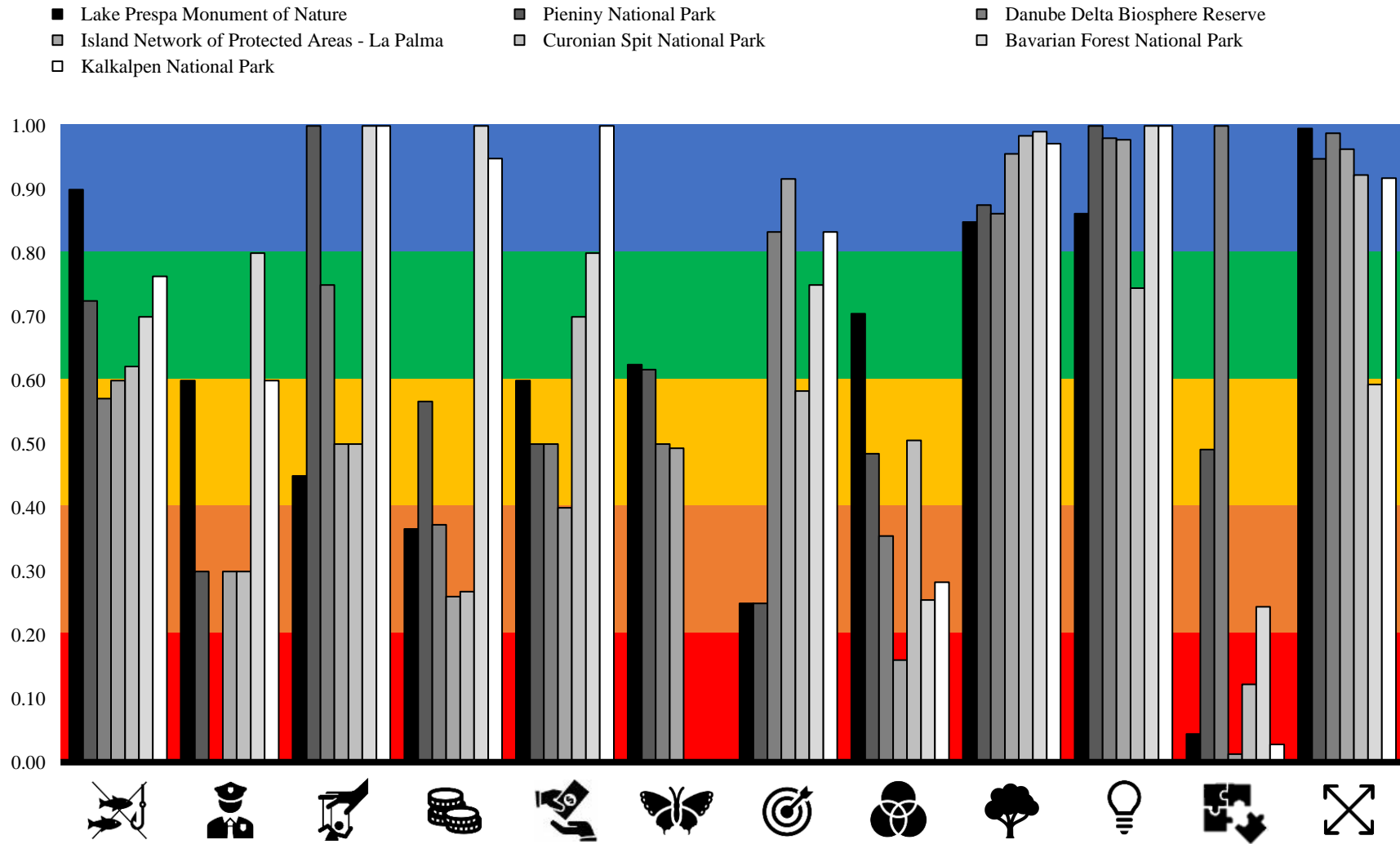
Figure 10. Scores for PLI sub-indices for all 7 PAs. Note that the Biodiversity sub-index could not be calculated for the Curonian Spit, Bavarian Forest and Kalkalpen National Park.

Funding

Illegal Activities Regulations

R² = 0.0872

Enforcement Employees

R² = 0.4899

Controlled Visitor Behaviour

R² = 0.7213

Illegal Activities Regulations

R² = 0.4271

Corruption Regulations

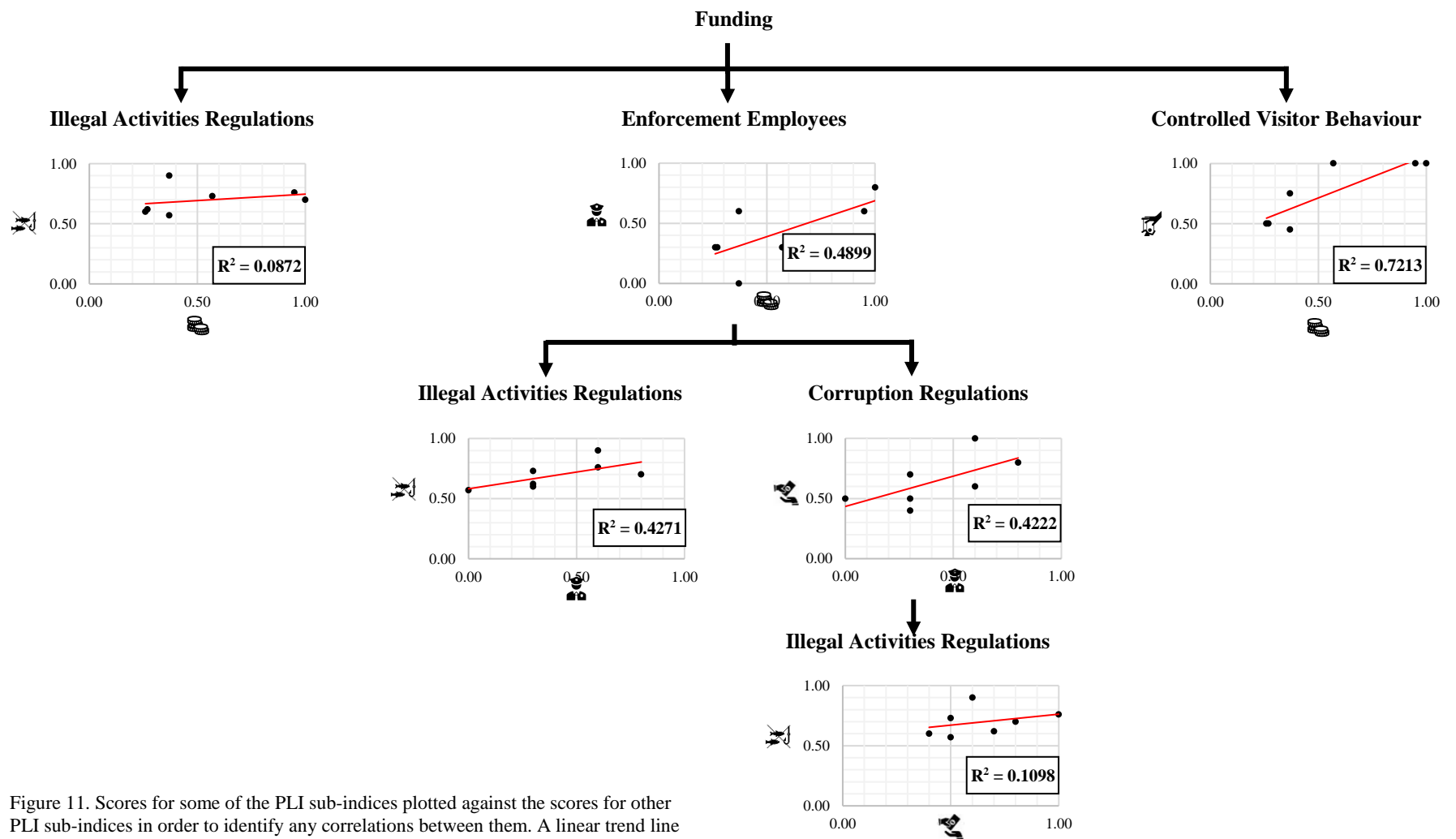R² = 0.4222

Illegal Activities Regulations

R² = 0.1098

Figure 11. Scores for some of the PLI sub-indices plotted against the scores for other PLI sub-indices in order to identify any correlations between them. A linear trend line has been fit through the data. The R squared values belonging to the linear fit are given in boxes.

4. Discussion

4.1 PLI as the new globally applicable PA effectiveness method

PA managers are under increasing pressure to determine the effectiveness of their PA in ways that are practical, scientifically sound and comparable among different PAs. Over the years, significant efforts have been made by different countries to develop and apply protected areas management effectiveness methodologies. However, the majority of these methods are not globally-applicable (Hockings & Phillips, 1999) and often do not focus on the effects of protection regulations in the field (Pomeroy, 2004). In this study we developed and tested a new index, the Protection Level Index (PLI), which evaluates the actual level of protection in the PA by assessing managerial, socio-economic and environmental factors in the PA.

We found that 7 European PAs with different managerial and environmental characteristics, show 7 different sets of scores for the PLI sub-indices, but still have a similar (midrange) final PLI score. The final PLI score value on itself does not give any information regarding its constituents. Therefore, the final PLI score must always be accompanied by the individual scores for the PLI sub-indices, which gives the PA manager a quick insight into which aspects of the PA have a high or low quality. Using equal weights for all sub-indices and using their average as the final PLI score results in the unbiased character of PLI. The average final PLI score for the 7 PAs is 0.64, which is very similar to the average score of 0.52 found on the common assessment scale developed by Leverington *et al.* (2010) in which 8163 worldwide PAs have been assessed. The first indication that PLI possesses the potential to be globally applicable to any type of PA.

One of the most commonly applied protected area management effectiveness methodologies is the Rapid Assessment and Prioritization of Protected Area Management (RAPPAM) from the WWF (Ervin, 2003a). Like PLI, the collection of data occurs via a questionnaire. The RAPPAM questionnaire is filled out during one or more participatory workshops at which PA managers, administrators and stakeholders discuss the questions, share their interpretations and agree upon the answers (Ervin, 2003b). RAPPAM encourages the incorporation of preliminary assessments and existing data such as aerial photos, satellite imagery, biodiversity reviews, anthropological and sociological studies, threat analyses and/or legal and policy reviews (Ervin, 2003b). However, in this way, the assessment of PAs using the RAPPAM method may be biased depending on the availability of such preliminary data. PLI does not require lengthy workshops and is not discriminatory towards the presence or absence of preliminary assessments and/or existing datasets. The PLI questionnaire takes up a maximum of 2 hours and the spatial analysis in GIS takes about 4 to 6 hours depending on the quality and resolution of the shapefiles.

The Management Effectiveness Tracking Tool (METT) developed by the World Bank/WWF Alliance (Stolton *et al.*, 2003) is the second most used PA effectiveness at present. The METT questionnaire consists of multiple choice questions for which the answers correspond to scores ranging from 0 to 3 (similarly for PLI scores range from 0 to 1). Like PLI, the METT questionnaire contains questions regarding the perception of the PA managers on aspects such as the adequacy of the number of staff and the amount of funding. In the METT method all questions are equally weighted and managers are allowed to exclude questions of which they believe are irrelevant for their PA. The final METT score is calculated as a percentage of the scores from those questions that were relevant to a particular PA. The developers of METT noted that this approach leads to limitations in terms of allowing comparisons between different PAs. While PLI mimics the approach of using equal weights for different factors, PLI does not allow for the exclusion of any of them. In this way, each PA is assessed on the exact same set of sub-indices, making PLI globally applicable to any type of PA.

The PA effectiveness method of Parrish *et al.* (2003) defines a conservation target as conserved (and thus assigned a maximum score) when all of its ecological attributes are maintained within an explicitly delineated range of variation, i.e. a range of optimal conditions. However, scientists and conservation planners have little confidence in quantitative descriptions of defining such acceptable ranges of variation for an attribute. In addition, chances are that PA managers do not possess the required information to define such ranges, let alone to rate them. In case of Parrish *et al.* (2003) these acceptable ranges of variation mainly concern aspects related to biodiversity, but such ranges are often also defined for non-ecological aspects such as acceptable ranges of park ranger densities or amount of park funding. One of the most innovative aspects of PLI is that it has a different way of dealing with the issue of predefining standard optimal conditions. In PLI the acceptable range of variation for (some of) its sub-indices are not predefined but instead determined by the perception of the PA manager. In this way, the PA

manager can place the conditions in context and assesses whether these conditions are optimal or not. The reason for this approach is that each PA is different and the optimal conditions for one PA might be insufficient for another PA and it is the rationale of PLI that the best assessor of this is the PA manager himself.

Even though many PA effectiveness methodologies claim to measure effectiveness, in theory these methods only give an assessment of the conditions of the PA at a specific point in time. Measuring effectiveness requires a timespan: the situation at a certain point in time must be compared to a previous situation in order to observe improvement/deterioration. Like for most PA effectiveness methods, PLI can be used to measure the effectiveness of the management of a PA by determining the PLI score of a PA at different points in time (on a yearly basis for example) and subsequently evaluate the evolution of the PLI score.

4.2 PLI and the IUCN categorising system

The IUCN Category is based on the primary management objective(s) that should apply to at least 75% of the PA. However, formulating management objectives does not automatically imply that those objectives are being met in reality. Where the IUCN Category is an assessment of the management strategy *itself*, PLI assess the *effects* of the management strategy of a PA. Therefore, PLI is a useful tool to identify "paper parks" and must be seen as complementary to the IUCN categorizing system.

4.3 Connections between PLI sub-indices

Results have shown that some scores of questionnaire based PLI sub-indices can be (partly) explained and deduced by the scores from other sub-indices. One of the most important drivers of success for a PA is the amount of funding it receives on a yearly basis. For example, hiring enforcement employees and building services that control the behaviour of PA visitors (e.g. pathways, parking lots, visitor centres) requires sufficient financial resources. This explains the positive correlations found between the Funding index and the Enforcement Employees index, and also between the Funding index and the Controlled Visitor Behaviour index. Moreover, a low score for the Enforcement Employees index leads to a low score for the Illegal Activity Regulations index as well. This is because a low enforcement employee density means a low surveillance intensity on human activities which allows for the occurrence of illegal activities. PLI revealed that discrepancies regarding controlling the behaviour of visitors and illegal activities can be traced back directly or indirectly via enforcement employees to the amount of funding. This gives PA managers an advantage when they approach funding agencies.

Regarding the spatial geometry of PAs we encountered two ways in which PAs deal with anthropogenic structures (e.g. cities, railways, traffic roads, etc.): the structures are either included or excluded from the PA. For example, excluding the anthropogenic structures is advantageous regarding the score for the Naturalness index, but disadvantageous regarding the Edge Effects index as it increases the total border length. The GIS-based PLI sub-indices have been developed in such a way that either in- or excluding anthropogenic structures does not generate an advantage regarding the final PLI score, because low scores for certain sub-indices will be (partly) balanced out by high scores for other sub-indices. As the final PLI score is not greatly affected by differently drawn PA borders, PLI is less susceptible to fraud.

4.4 Future recommendations

The Illegal Activity Regulations index and the Management Objectives index are both indices based on a list of predefined criteria. The illegal activities list (Table 1) might require future consideration in order to ensure its completeness and its universal character to be applicable to any type of PA, marine and terrestrial. In the same way the list of the management objectives (Table 10) needs future examination as some of the objectives listed here are not applicable to any type of PA.

The scores for the Enforcement Employees index, the Funding index and the Corruption index strongly depend on the perception of the PA manager. A drawback of this approach is that the perception of a PA manager is subjective and may not always correctly reflect the reality. For example, the perception of a low occurrence of illegal activities or a low level of corruption, might be because the manager is unaware of such activities. Also, including perceptions makes the final PLI score relatively sensitive to who is interviewed, as each person is differently opinionated. Even though it remains risky to rely on the perception of people, it is preferred over assessing scores based on fixed optimal conditions that are not widely applicable.

The Biodiversity index of PLI assess the effort put in by managers to monitor and safeguard the biodiversity in the PA. The reason why PLI does not assess the biodiversity of the PA is because there is no widely accepted method on how to measure biodiversity and it is outside the scope of this study to develop a whole new biodiversity method. If in the future a globally accepted method for measuring biodiversity would arise, then the Biodiversity index of PLI might need adjustments. However, it remains challenging to address a score to the biodiversity of an area as, for example, a healthy tropical rainforest ecosystem has a much higher biodiversity than a healthy desert ecosystem.

Finally, not all PLI sub-indices are as suitable for marine PAs as they are for terrestrial PAs. Even though attempts have been made to identify the marine equivalents of terrestrial components in PLI, e.g. aquaculture for agriculture and shipping lanes for traffic roads, future efforts might be needed to improve the applicability of PLI to any type of PA.

5. Conclusion

The Protection Level Index (PLI) is a new Protected Area (PA) effectiveness method that allows for a quick and simple assessment of the degree of protection in any type of PA in the world. It complements the IUCN categorizing system, in that the IUCN Category assesses the management strategy (on paper) and PLI assesses the actual effects of this management strategy in the field. This makes PLI capable of identifying so called "paper parks". The final PLI score ranges from 0 (undesirable) to 1 (desirable) and is the average score of 12 equally weighted sub-indices. These sub-indices are a selection of globally recognized indicators of PA management effectiveness. The score for 7 of the sub-indices is based on the results from the PLI questionnaire (~2 hours) and the other 5 are based on the spatial characteristics of the PA and are computed in a GIS analysis (4 – 6 hours). PLI has been tested in 7 European PAs: Lake Prespa Monument of Nature, Pieniny National Park (Slovakia), Danube Delta Biosphere Reserve, Island Network of Protected Areas - La Palma, Curonian Spit National Park, Bavarian Forest National Park and Kalkalpen National Park. Despite the different environmental regimes and the dissimilarities between these 7 PAs, they all have similar midrange final PLI scores around 0.64. The final PLI must always be considered together with the individual scores for the sub-indices in order to identify the strengths and weaknesses of the PA. Apart from being faster than RAPPAM (WWF) and more widely applicable than METT (World Bank/WWF Alliance), PLI also introduces a new way of incorporating the perception of the PA manager in the scoring and thereby omits the issue of pre defining universal optimal conditions. In conclusion, PLI can be a useful tool for PA managers as it offers a quick and simple assessment of the effects of the current management strategy for any type of PA worldwide.

6. Acknowledgements

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Appendix A – PLI questionnaire

Developing the
Protection Level Index (PLI)

Protection Level Index

Survey

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Part of the EcoPotential Project

Table of Contents

Privacy Statements

In this survey you are requested to provide some personal information (name, email, telephone, address details, affiliation) to EcoPotential.

EcoPotential and its partners respect the privacy of all the participants to the survey.

EcoPotential and its partners ensure that all personal information:
    …shall never be provided to third parties without your explicit unambiguous consent.
    …shall be excluded in case you did not agree on sharing that information.

To this end, we ask you, in advance of the survey, to declare your preferences regarding the handling of the personal information.

List of participants:

………………………………………………………………………

………………………………………………………………………

………………………………………………………………………

………………………………………………………………………

………………………………………………………………………

………………………………………………………………………

………………………………………………………………………

………………………………………………………………………

	Accessible for EcoPotential partners		**Accessible for third parties**	
Personal information	☐ yes*	☐ no**	☐ yes*	☐ no**
General information	☐ yes***	☐ no****	☐ yes***	☐ no****

*   You authorise the use of your name in any future publications in which the results of this survey are used

**   You do not authorise the use of your name in any future publications in which the results of this survey are used (you stay anonymous)

***   You authorise the use of your answers to this survey

****   You do not authorise the use of your answers to this survey

Disclaimer

The content of this survey has been compiled with the utmost care in the frame of the EcoPotential project.

Responsible partners for this survey are Yvette Agnes Maria Mellink (BSc), Christiaan Hummel (MSc) and Prof. Dr. Herman Hummel of the Royal Netherlands Institute for Sea Research (NIOZ), Yerseke, the Netherlands.

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1. General Information of the Protected Area

A. Official name

What is the official name for the Protected Area in question?

……

B. Location

In which country/countries is the Protected Area located?

……

C. Year of foundation

In which year was the Protected Area established? (in case of multiple foundation years, please signify the oldest year)

……

D. IUCN Category

If applicable, what IUCN Category has been assigned to the Protected Area?

……

E. Surface area

What is the total surface area of the Protected Area?

…………………………………………………………………………………………… hectares

F. Circumference

What is the circumference of the Protected Area following the outline of the border?

………………………………………… *indicate unit!*

G. Shapefiles & satellite imagery

Can you provide us with a *shapefile* of the Protected Area?

☐ Yes

☐ No

Can you provide us with *satellite imagery* of the Protected Area?

☐ Yes

☐ No

2. Illegal Activity Mitigation Index

GAME #1

A. Presence of illegal activities

Indicate for each activity listed below, whether this activity is illegal or not in the Protected Area (PA).

In case an activity is illegal, indicate to which extent this activity takes place in the Protected Area

1. This illegal activity takes place to a negligible extend
2. This illegal activity takes place to a small extend
3. This illegal activity takes place to a moderate extend
4. This illegal activity takes place to a large extend
5. This illegal activity takes place to a very large extend

	Legal activity	Does not take place in the PA	1	2	3	4	5
Agriculture/Aquaculture	☐	☐	☐	☐	☐	☐	☐
Commercial extraction of wild biological resources	☐	☐	☐	☐	☐	☐	☐
Non-commercial extraction of biological resources	☐	☐	☐	☐	☐	☐	☐
Building infrastructure	☐	☐	☐	☐	☐	☐	☐
Recreation	☐	☐	☐	☐	☐	☐	☐
Poaching	☐	☐	☐	☐	☐	☐	☐
Extraction of non-renewable natural resources	☐	☐	☐	☐	☐	☐	☐
Drone flights	☐	☐	☐	☐	☐	☐	☐
Motorized access	☐	☐	☐	☐	☐	☐	☐
Littering	☐	☐	☐	☐	☐	☐	☐
Vandalism	☐	☐	☐	☐	☐	☐	☐

3. Enforcement Index

A. Number of enforcement employees

How many enforcement employees[1] are currently working/present in your PA?

……………………………………………………………………………………………………

B. Sufficiency of enforcement employees

Indicate to which degree the number of enforcement employees currently at your service, is sufficient in order to ensure well-functioning of the PA

☐   The number of enforcement employees is <u>way too low</u> in order to ensure well-functioning of the PA

☐   The number of enforcement employees is <u>slightly too low</u> in order to ensure well-functioning of the PA

☐   The number of enforcement employees is <u>adequate</u>

☐   The number of enforcement employees is <u>slightly too high</u> in order to ensure well-functioning of the PA

☐   The number of enforcement employees is <u>way more than needed</u> in order to ensure well-functioning of the PA

---

[1] Person that is authorized to arrest and/or enforce a penalty on an offender of the rules of the PA

4. Visitor Index

A. Number of visitors

How many visitors visit the Protected Area in one year on average?

………

B. Entrance ticket price

What is the entrance ticket price?

☐   Free entrance

☐   Ticket prices:

         ………………………………………………………………………

         ………………………………………………………………………

         ………………………………………………………………………

         ………………………………………………………………………

5. Controlled Visitor Behaviour Index

A. Visitor accessibility

Can visitors enter (and exit) the Protected Area at any location along the border?

☐   No,   the Protected Area is fully fenced and can only be accessed via a limited number of entrances

☐   Yes,   the PA has no fence and can be accessed everywhere

☐   Yes,   the PA has no fence, but we concentrate visitors by using designated entrances (e.g. parking lots, public transport connections, visitor centres, harbours)

B. Paths

Are there any paths / shipping-lanes present in the Protected Area?

☐   No,   visitors are allowed to distribute randomly over the area

☐   Yes,   visitors are expected to stay on these paths / shipping-lanes

C. Indicated routes

What percentage of the paths / shipping-lanes is part of specified routes indicated with directional signs?

…………%

6. Funding Index

A. Gross National Income per capita

What is the Gross National Income (GNI) per capita of the country in which the Protected Area is located?

…………………………………   *indicate currency!*

B. Available funding

How much funding does the Protected Area receive?

………………………………… per year   *indicate currency!*

C. Funding perception

Is the funding that you receive sufficient in order to execute proper management that results in a well-functioning Protected Area?

☐   Absolutely insufficient,   critical lack of funding

☐   Partly insufficient,   the PA management can go on but there is still a big lack of funding

☐   Sufficient,   all management actions can be executed

☐   More than sufficient,   enough funding for proper management and some additional actions

☐   Superfluous,   more than enough funding for management and many additional actions

7. Corruption Index

A. Corruption Perception Index (CPI)

What is the most recent Corruption Perception Index published by the Transparency International organization for the country in which the Protected Area is located?

………………

B. Corruption in reality

Does the CPI give a good representation of the level of corruption in reality?

☐   No,   the level of corruption is   much higher than   indicated by the CPI

☐   No,   the level of corruption is   slightly higher than   indicated by the CPI

☐   Yes,   the level of corruption is   correctly   indicated by the CPI

☐   No,   the level of corruption is   slightly lower than   indicated by the CPI

☐   No,   the level of corruption is   much lower than   indicated by the CPI

8. Biodiversity Index

A. Measuring biodiversity

Do you measure the biodiversity in the Protected Area?

☐   Yes

☐   No   →   please continue at subsection D

B. Classes

Which classes of species/taxa do you use for measuring biodiversity in the Protected Area?

……

……

……

C. Reference situation

Do you have a historical reference for the biodiversity in the Protected Area?

☐   Yes

☐   No   →   please continue at subsection D

If yes, for what species/taxa do you have historical biodiversity data?

………

………

………

Please estimate, for each group, what percentage of the historical biodiversity (reference) situation is currently present in the Protected Area

……………………………… %

……………………………… %

……………………………… %

……………………………… %

D. Invasive species

Are there any invasive species in the Protected Area?

☐ Yes

☐ No

If yes, do the invasive species, in your opinion, have an overall positive or negative impact on the ecosystem in the Protected Area?

☐ Positive

☐ Neutral

☐ Negative

9. Traffic Index

No interview questions

10. Edge Effect Index

No interview questions

11. Naturalness Index

No interview questions

12. Expandability Index

No interview questions

13. Light Pollution Index

No interview questions

14. Fragmentation Index

No interview questions

15. Management Objectives Index

GAME #2

A. Management plan

Do you have a management plan?

☐   Yes

☐   No

B. List of management objectives / what do you manage by?

Indicate for each management objective, whether it is included in the official management plan of the Protected Area

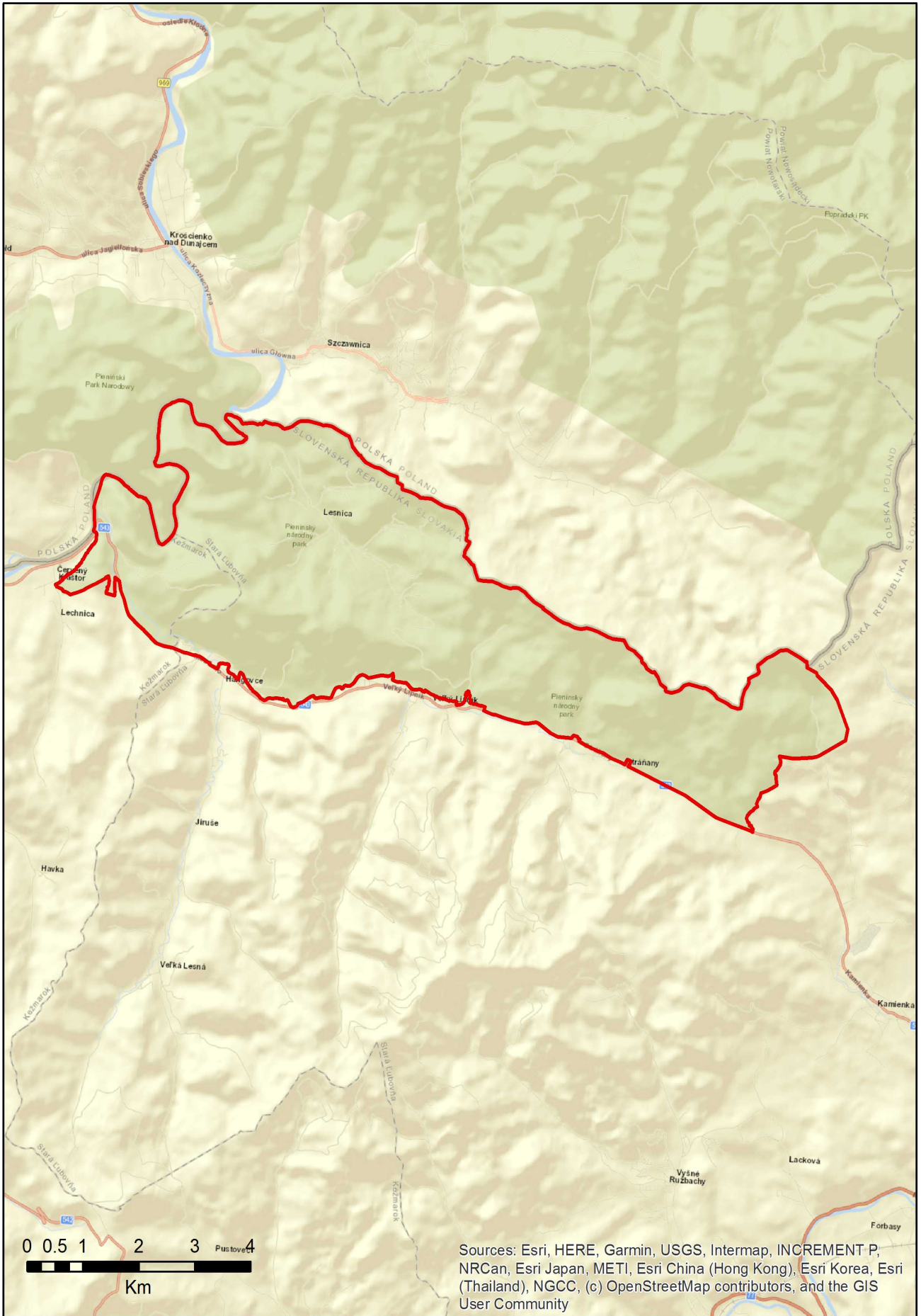|	Present in management plan	Not present in management plan
Protection of endangered species	☐	☐
Protection of a nationally significant landscape	☐	☐
Protection of ecosystem services	☐	☐
Protection of cultural sites	☐	☐
Protection of natural resources for sustainable use	☐	☐
Providing food or other products for the markets/ Provide benefits to the local and national economy	☐	☐
Maintaining natural processes	☐	☐
Preserve significant natural features	☐	☐
Safeguard the genetic diversity	☐	☐
Provide recreation and tourism services	☐	☐
Provide education, research and environmental monitoring	☐	☐
Provide homes to human communities with traditional cultures and knowledge of nature	☐	☐

Thank you for your co-operation!

Appendix B – Borders of the 7 Protected Areas used in this study

B.1 **Lake Prespa Monument of Nature**

А2

Единаково
Edinakovo

Дебарца Debarca
Охрид Ohrid

Демир Хисар
Demir
Hisar

Е-65 А3

R1305

Лопатица
Lopatica

Лескоец
Leskoec

Велгошти
Velgoshti

R1208

Охрид
Ohrid

Рамне
Ramne

Рача
Racha

ПЕЛАГОНИСКИ ПЕЛАГОНИСКИ

Ресен
Resen

Горњи Дупен
Gornji Dupen

R1101 Е-65 А3

Цапари Ротино
Capari Rotino

Трново
Trnovo

Дoња Бела црква
Donja Bela crkva

Пештани
Peshtani

R1307

Преспанско Езеро
Prespansko Ezero

Сливница
Slivnica

ero

R232

Стење
Stenje

Преспанско Езеро
Prespansko Ezero

Крани
Krani

Штрбово
Shtrbovo

Љубаништа
Ljubanishta

Korçë Korce
Pogradec

Долно Дупени
Dolno Dupeni

Ресен Resen

SHQIPERIA ALBANIA ΕΛΛΑΔΑ GREECE

Prespa
e Madhe

Πρέσπες
Prespes

Vreshtas

SH79

Liqenas

Καλλιθέα
Kallithea

15

Εθνικός Δρυμος Πρεσπων
Ethnikos Drymos Prespon

Μικρή Πρέσπα
Mikri Prespa

Πρέσπες
Prespes

0   1.75 3.5   7   10.5   14

Km

B.2   **Pieniny National Park**

B.3   Danube Delta Biosphere Reserve

Cahul

U.T.A. Găgăuzia

Taraclia

Kalcheva

Vulcanesti

MOLDOVA

Cahul

UKRAINE

Reni

Ozero Kagul

Luncavita

Jijila

Macin

Niculitel

Carcaliu

Cerna

Peceneaga

Topolog

Daeni

Tulcea

Saraiu

Casimcea

Topalu

Cernavoda

Nicolae Balcescu

Medgidia

Lumina

Cogealac

Constanta

Techirghiol

Ozerne

Ozero Yalpug

Izmail

ROMANIA

Ozero Katlabukh

Shevchenkove

Kiliiskyi raion

Vylkove

UKRAINE
ROMANIA

Sulina

Rezervatia Biosferei Delta Dunării

Lacul Rosu

Sarichioi

Babadag

Lacul Razelm

Rezervatia Biosferei Delta Dunării

Lacul Sinoe

0 5 10 20 30 40
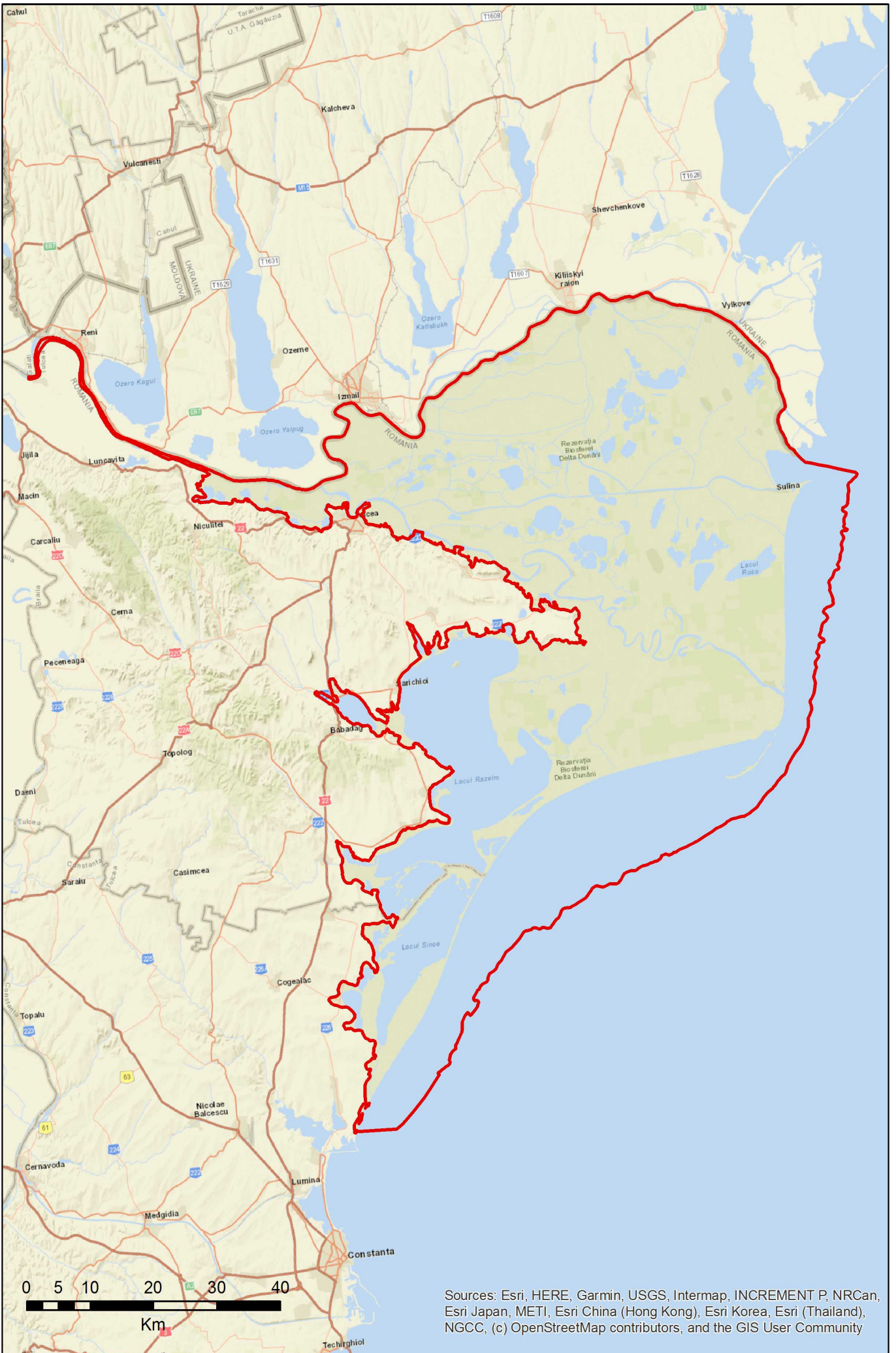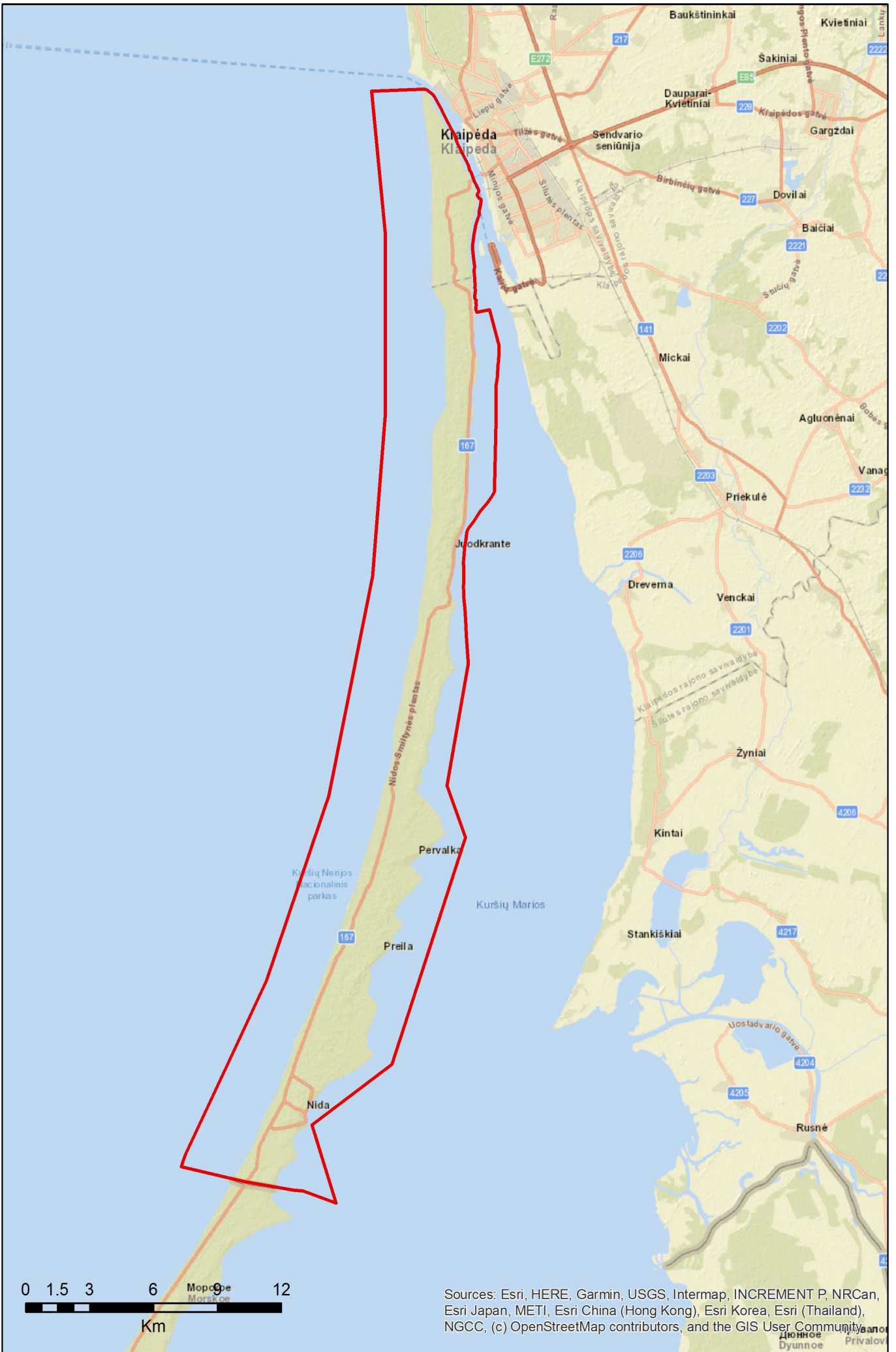Km

Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan,
Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand),
NGCC, (c) OpenStreetMap contributors, and the GIS User Community

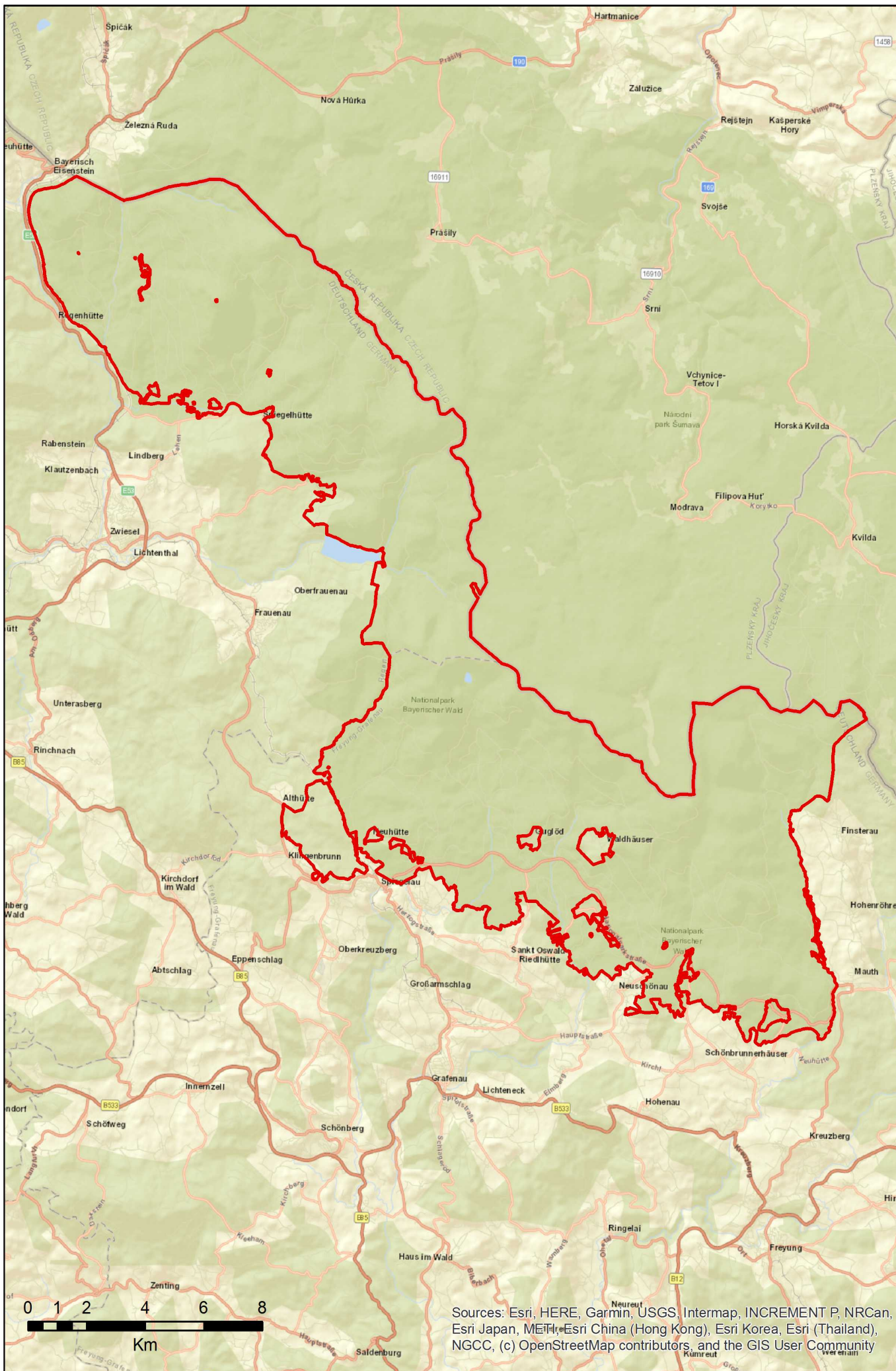**B.4   Island Network of Protected Areas- La Palma**

Garafía

LP-112

Cueva
del Agua

LP-101

Llano Negro

Parque
del Faro

Barlovento

LP-110

LP-109 LP-1

San Andrés y
Sauces

Hoya Grande

Briestas

LP-1

El Pinar
Puntagorda

LP-115   LP-113

Vereda de
las Lomadas

LP-104

LP-111

Tinizara

Las Nieves

Parque Nac.
Caldera de
Taburiente

El Granel

Puntallana

LP-102

Tijarafe

LP-116

LP-118

LP-7

Amag

Montaña
Tenisca

Los Llanos
de Aridane

Tazacorte
Marina

El Paso

Las Norias

LP-125

Jedey

LP-1

El Remo

Cumbre Vieja

Tiguerorte

LP-103
LP-101

Lomo del
Centro

Santa Cruz
de La Palma

Breña Alta

Breña Baja

LP-5

Villa de Mazo

LP-205

LP-132

El Poris

as Indias

Las Caletas

Fuencaliente
de La Palma

LP-130

Salinas de
Fuencaliente

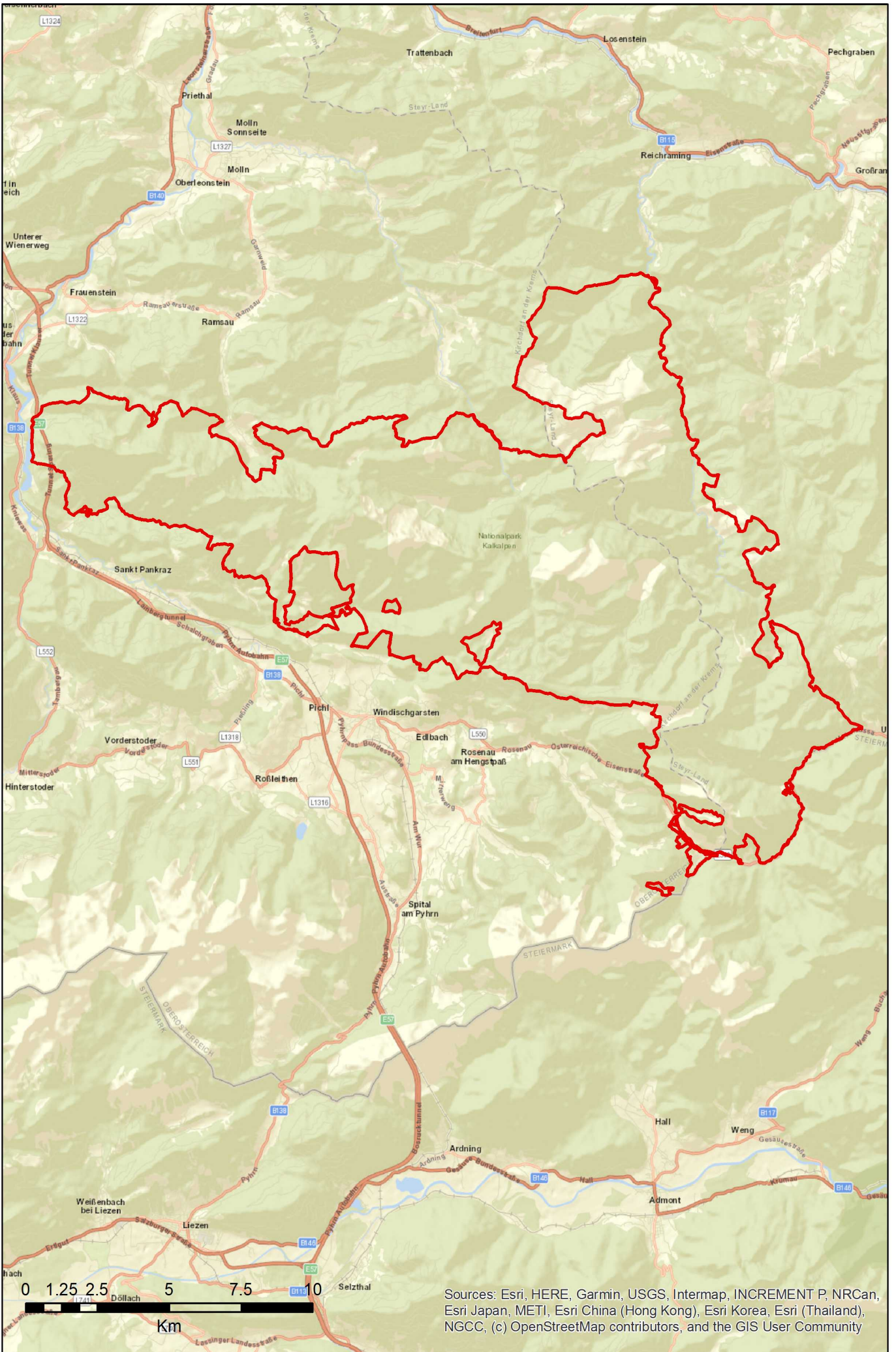0   1.5   3   6   9   12

Km

Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT
P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri
Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors,
and the GIS User Community

B.5 Curonian spit National Park

B.6   Bavarian Forest National Park

B.7   Kalkalpen National Park