YRKESHÖGSKOLAN NOVIA

Protection of the Natura 2000 Habitat Coastal Lagoons and Glolakes in Finland

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Abstract

Coastal lagoons are a Natura 2000 protected habitat mentioned in the European Union's habitats directive annex I. The interpretation manual for European Union habitats mentions Flads and gloes as a Baltic variety of coastal lagoons. The flads and gloes on the land uplift coast are a special responsibility habitat for Finland and are classified as vulnerable.

In flad development the shallow bays slowly become more isolated from the marine environment due to land uplift via different succession stages. The natural development can however be disturbed by human activities and therefore protection is needed.

The different stages of coastal lagoons in Finland are varyingly protected by two different laws. Nature conservation act offers area-based protection of many development stages inside natura protected areas and water act protects many development stages if they are in natural condition and have an area smaller than 10 hectares.

This thesis used a spatial analysis with a classification of lagoon development stages, an anthropogenic pressure layer and the natura 2000 protected areas applied to information about the legislation that concerns the protection of lagoons to assess the protection level of different stages of coastal lagoons.

The result was that juvenile flads, the first stage in the development were the least protected and one of the most under anthropogenic pressures. When accounting for the natural succession this could lead to a smaller number of lagoons being in natural condition in the future along with a lowered level of protection.

Language: English
Key Words: flad, glo, lagoon, conservation, habitat

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Tiivistelmä

Natura luontotyyppi 'rannikon laguunit' on Euroopan unionin luontodirektiivin liitteen I luontotyyppi, johon luetaan Itämerellä fladat ja kluuvit. Maankohoamisrannikon Flada-kluuvi kehityssarjat taas on Suomen kansainvälinen vastuuluontotyyppi, jonka tila on arvioitu vaarantuneeksi. Fladojen kehityksessä maankohoamisen seurauksena matala merenlahti erkaantuu hiljalleen merestä eri kehitysvaiheiden kautta. Tämä kehitys saattaa kuitenkin häiriintyä esimerkiksi ihmisen toiminnan seurauksena, minkä vuoksi tarvitaan suojelua.

Rannikon laguunien eri kehitysasteita koskee vaihtelevan tasoinen, kahdella eri lailla tapahtuva suojelu. Luonnonsuojelulailla suojellaan suurinta osaa kaikista natura-alueilla sijaitsevia laguuneista ja vesilain piiriin kuuluvat kaikki esifladan jälkeen tulevat kehitysasteet, mikäli ne ovat luonnontilaisia ja alle 10 hehtaaria pinta-alaltaan.

Tässä työssä käytettiin paikkatietoanalyysiä laguunien kehitysasteluokittelun, ihmispainetason ja Natura 2000 alueiden kanssa ja tätä tietoa sovellettiin lakiin laguunien suojelutason selvittämiseksi eri kehitysasteilla.

Tuloksena voitiin todeta, että laguunien ensimmäisestä kehitysasteesta, esifladoista on suojeltu kaikkein pienin osuus ja niihin kohdistuu huomattavaa ihmistoiminnan aiheuttamaa painetta. Kehityksen jatkuessa tämän voi tulevaisuudessa katsoa johtavan luontotyypin luonnontilaisuuden heikkenemiseen ja suojelun tason alenemiseen myös myöhemmissä kehitysasteissa esifladojen kehittyessä ensin fladoiksi ja sitten myöhemmiksi kehitysasteiksi.

Kieli: Englanti
Avainsanat: flada, kluuvi, laguuni, luonnonsuojelu, luontotyyppi

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1 Introduction

The pressures on marine environments are increasing, as the production of energy and renewable resources are often concentrated on coastal zones. In the European Union these questions are managed by the Directive for Maritime Spatial Planning (Council directive 2014/89/EU). The European Union also requires its member states to strive for a good status of all their ground and surface waters, including coastal waters in the Water Framework Directive (2000/60/EC). This is implemented by the national Marine Strategy (Valtioneuvoston kanslia, 2019).

Marine spatial planning aims to support growth in the marine areas by offering a tool for sustainable management of marine areas while the pressure to develop coastal areas grow. To improve the ability to make these plans, information on the locations of the most ecologically important marine environments is needed to be able to preserve them.

Coastal lagoons (Figure 1) are special responsibility habitat type for Finland, and they are listed as vulnerable (VU) in the red list of habitats. They are often a hotspot of underwater vegetation biotopes with a high coverage of charophytes and submerged vascular plants. These communities offer shelter and nourishment for fish and invertebrates that in turn attract migrating birds. Coastal lagoons house many threatened species (*Chara braunii, Hippuris tetraphylla, Potamogeton friesii*) and the threatened habitat sheltered Charophyte meadows (Kotilainen et al., 2020).

Figure 1: A lagoons complex in Sundom, Ostrobothnia. ©Jaakko Haapamäki/Metsähallitus

My thesis aims to combine methods used in the project Kvarken Flada, that took place from 2017 to 2020, where lagoons in the Quark region were classified and extensive field studies were carried out, and the ongoing project "Tila2", in which the state of marine protection is currently studied. The study area includes Finlands' coastal regions, as a new lagoon dataset was produced in Tila2 and Tila3 projects during 2021. This enables an analysis of the protection status of different stages, area classes and natural condition of lagoons.

In short, the aims of the thesis are:

- To classify coastal lagoons in Finland by their development stage
- To assess the protection level of different stages of lagoon development
- To determine the most vulnerable development stages based on human activities and level of protection

2 Background

Coastal lagoons are a Natura 2000 protected habitat mentioned in the European Union's habitats directive annex I. The interpretation manual for European union habitats mentions flads and gloes as a Baltic variety of coastal lagoons, but there are several different development stages in the flad-glo development series (Figure 2). In Finnish legislation and guidelines, it is common to use terms flad or flads and gloes to describe the different development stages, but they can also mean individual stages in the development of these shallow bays. To have a clear term to describe all the different development stages as whole, lagoon is preferred here. There are also different practices in naming the different stages in flad-glo development series and sometimes glo-lake is used as synonymous to glo (Wistbacka, 2014; Kotilainen et al., 2020). Here, however the classification used by Munsterhjelm (1997) is preferred as it identifies the four main stages in the development series. These are juvenile flad, flad, glo-flad and glo. The fifth stage would be glo-lake, but it is usually not considered in marine conservation, as it is outside the impact of the marine environment. It is, however, mentioned in the water act as a protected water body.

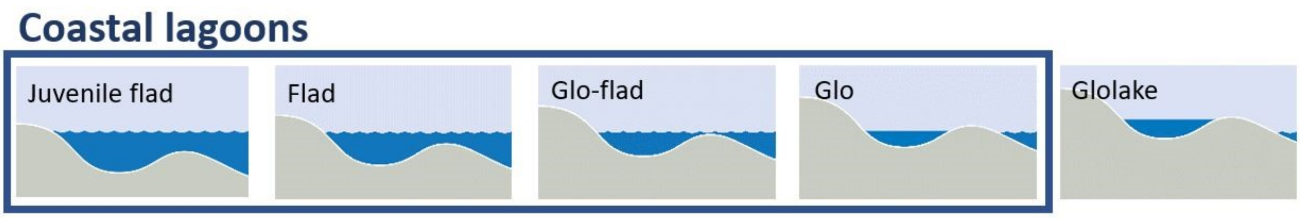

Figure 2: Main flad development stages by Munsterhjelm. Stages identified as Coastal lagoons inside a blue rectangle.

As lagoons are an outcome of land upheaval and the phenomenon is still ongoing in Finland, the development stages of lagoons are constantly changing; new juvenile flads emerge from the sea and old glo-lakes slowly turn into lakes and later into marshes, if they are left undisturbed. The development may seem slow, but changes are inevitable and need to be accounted for. The development stage and anthropogenic pressures affect the protection status, so up to date information is needed to make assessments about the state of lagoons.

2.1 Nature values

Coastal lagoons are water bodies where the connection to the sea has been reduced due to emergent vegetation or a threshold. Lush communities of charophytes *(Chara sp.)* and naiads *(Najas sp.)* (Figure 3) being abundant along with the more common communities of pond weeds *(Potamogeton spp., Stuckenia spp.)* in southern Finland also eelgrass *(Zostera marina)* can occur. (Airaksinen & Karttunen, 2001). Lagoons are also important fish spawning areas (Wistbacka & Snickars, 2000), are a good habitat for insects (Ilvessalo-Lax & Mikkola, 2019) and are often also important bird migrating and nesting areas (Airaksinen & Karttunen, 2001).

Figure 3: Lush communities of Naiads (Najas sp.) and Charophytes (Chara sp.) in a lagoon in Sweden. ©Anniina Saarinen/Länsstyrelsen Västerbotten

2.2 Vegetation

The lush vegetation in lagoons binds nutrients and stabilises sediments. It also provides shelter for many invertebrates and the later stages in the development often act as spawning grounds for different species of fish. This in turn attracts birds making lagoons an ecological hotspot.

2.2.1 Vascular plants

The submerged vegetation in lagoons is often rich (Figure 4) and diverse and usually consists of pond weeds (*Potamogeton spp., Stuckenia spp.*), naiads (*Najas sp.*), and watermilfoils (*Myriophyllum sp.*) (Airaksinen & Karttunen, 2001). The species are often not rare or endangered but the communities they form can be ecologically valuable as they offer shelter and food for many invertebrates and fish (Hansen, 2012).

Figure 4: Vascular plants in lagoons often form rich communities. ©Roosa Mikkola/Metsähallitus

The reed belt is often prominent, and even though the common reed *(Phragmites australis)* is not important as a species, it provides shelter for fish, stabilizes bottom sediments, and binds nutrients.

2.2.2 Charophytes

Charophyte communities are common in lagoons (Figure 5) and as sheltered charophyte communities are classified as vulnerable in the red book of habitats (Kotilainen et al., 2020) the occurrences of charophytes in lagoons are of special interest in nature protection. Charophytes bind nutrition effectively, stabilize bottom sediments and offer shelter for fish and invertebrates.

Figure 5: The charophyte coral stonewort (Chara tomentosa) seen from the surface. ©Roosa Mikkola/Metsähallitus

2.3 Fish

As a lagoon becomes more sheltered in its later stages in the development, it becomes warmer compared to more open bays, especially in the spring. This in turn increases early production in the lagoon as the vegetation and invertebrates' gain from the elevated temperatures after winter, turning the area into a good site for spring spawning fish. A single lagoon's fish production is not very important regionally, but they can make a difference locally, especially if they are numerous (Saarinen et al., 2021).

2.4 Birds

Many migrating birds use lagoons as resting and feeding sites, as they are often rich in invertebrates and schools of juvenile fish. Waders and many ducks often take advantage of shallow lagoons for staging outside migrating periods and a well-functioning lagoon can sustain many different species making it a diversity hotspot (Ilvessalo-Lax & Mikkola, 2019).

2.5 Ecosystem services

There are also several benefits that lagoons provide to humans. These are called ecosystem services. There are several different ways to classify these benefits, for example Naturvårdsverket (2015) describes four different classes of ecosystem services: supplying, regulating, cultural and supportive. To make it easier to understand the differences between different classification systems and even move between them, the European Environmental Agency (EEA) has developed a classification system to integrate them, which is called the Common International Classification of Ecosystem Services (CICES).

Ecosystem services in lagoons can be divides into four main categories by the latest version of CICES 5.1 (Haines-Young & Potschin, 2018):

- Provisioning
- Regulation and maintenance
- Cultural

The classification of ecosystem services provides a means to give value to different functions that nature provides that might otherwise be taken for granted. This makes it easier to compare the economic effects of for example economic activities that disturb these functions and nature conservation.

The state of an ecosystem is often evaluated by the species distribution but as with many complex nature types, concerning lagoons it is important to assess if it is functioning correctly. These functions are called ecosystem services.

There are many benefits to be gained from lagoons as they for example maintain fish stocks, offer flood protection, and provide recreational possibilities. To describe the different functions, the EEAs CICES is used to group them in their respective main categories.

2.5.1 Provisioning ecosystem services

Lagoons are especially important for fish stocks of predatory fish as they act as recruitment areas for many of these species, such as perch (*Perca fluviatilis*) and pike *(Esox Lucius*) (Figure 6). Predatory fish are commercially important, and they offer further services as they regulate other fish stocks (Saarinen, 2019).

Figure 6: A Pike (Esox lucius) lurking in lagoon vegetation. ©Anniina Saarinen/Länsstyrelsen Västerbotten

There used to be more commercial uses for charophytes in for example agriculture in the past, but less nowadays. This is still a possibility as is the use of Charophytes in medicine and for example water purification (Gundersen et al., 2016).

2.5.2 Regulation and maintenance ecosystem services

There are many services that offer regulation and maintenance created by lagoons. These include the maintenance of resilience, carbon storage, removal of nutrients and water filtering.

Resilience is a measure of the pressures an ecosystem can withstand before collapse. Resilience can be for example species diversity or genetic diversity and the loss of these could often lead to losing productivity in the lagoon (Gundersen et al., 2016).

As charophytes are abundant in lagoons and they can bind carbon effectively, it is often stored as sediment in the bottom of lagoons making them an effective carbon sink. The combined effects of carbon binding in Baltic Sea lagoons have not been studied extensively but have the potential to be important (Gundersen et al., 2016).

Eutrophication is a large problem in the Baltic Sea and decreasing nutrient concentrations in the water is of great importance in the region. Vegetation in the lagoon effectively binds nutrients from the water as the lagoons are often shallow and rich in their vegetation coverage. Vegetation also acts as a filter for particles and lagoons can effectively reduce the load from land-based activities such as forestry and agriculture (Ilvessalo-Lax & Mikkola, 2019).

2.5.3 Cultural ecosystem services

Leisure time activities such as fishing, boating, and swimming are common in lagoons as they are often sheltered areas and are often natural harbours (Figure 7). Along with tourism they are examples of cultural ecosystem services. It should be noted that cultural services can be in contrast with other services as for example boating in shallow areas can have a negative effect on vegetation in a lagoon diminishing its regulatory and even provisional functions.

Figure 7: Lagoons are often natural harbours that attract human activities. ©Jaakko Haapamäki/Metsähallitus

2.6 Human activities

Due to the characteristics of the coast caused by land upheaval in Finland, lagoons are often subjected to human activities and pressures from summer cottages and related leisure time activities (figure 8), such as boating (Saarinen, 2019). This also increases the need for dredging. Especially the threshold of the lagoon is vulnerable to dredging, as modification can drastically change the water flow in and out of the main pool (Saarinen, 2019). Lagoons are usually shallow, and the bottom sediment is sensitive to disturbance making it susceptible to propeller streams, further accentuating the threats from boating-related activities. Activities in the catchment area, such as forestry, agriculture and ditching also cause pressures on the ecosystem in terms of increased nutrient and particle loads.

Figure 8: Human activities in a lagoon. ©Jaakko Haapamäki/Metsähallitus

2.7 Legislation

In Finland coastal lagoons are currently protected by the Nature Conservation Act (1096/1996) that implements the European Natura 2000 network and the Finnish Water Act (587/2011). Natura 2000 is a network of protected habitats in the European Union, and its aim is to preserve these threatened environments.

As the interpretation manual of European Union habitats (European Commission, 2013) leaves the interpretation of habitats to each individual member state and mentions only two development stages out of the possible five, there is plenty of room for interpretation as is evident by differences between national guides for interpretation.

The Water Act (587/2011) aims to protect small water bodies in Finland, and the act partly concerns lagoons, as it protects natural flads and glo-lakes smaller than 10 hectares. It is interpreted to also include glo-flads and gloes, but not juvenile flads. The difference to the protection provided by the Nature Conservation Act, that is based on conservation areas, is that the Water Act provides protection to all water bodies that fulfill the conditions, and not only those inside protected areas.

2.7.1 Comparison of lagoon protection in Sweden

The lagoons in Finland can only be compared with the ones in the northern part of the Baltic coast of Sweden as they develop similarly. Swedish interpretation of the Natura habitat differs a little from the Finnish one and the legislation is obviously not quite the same, but the data gathered in the project Kvarken Flada (Mikkola et al., 2020) can be used for comparison of the levels of pressure in lagoons for the two countries.

Legislation differs in Sweden in that they are protected only by the environmental code or 'Miljöbalk' (1998:808) that restricts building closer than 100 m from the shore. The habitat is classified as prioritized and there are national and regional guidelines for their management. In practice the coastal protection seems to be working in Sweden as the percentage of lagoons (not accounting for glo lakes) in natural condition was 35 compared to 17 in the study area in the project Kvarken Flada (Mikkola et al., 2020)

3 Methods

The main analysis was done using two new datasets that are based on orthophotos and the national Natura protected area shape. All three datasets are available for download in Finnish Environment Institutes Velmu -portal.

Lagoons 2021

The dataset includes information on lagoons and glo-lakes including development stage, status of threshold and area. It was made in tila2 and tila3 projects during 2021 and is based on aerial photos from Finnish land survey. The data has 7889 lagoons and glo lakes from the Finnish coast.

Human activities

The human activities dataset includes information on human activities visible in aerial photos including dredgings and piers. It was made in tila2 and tila3 projects in 2020. The dataset was used to determine the natural condition of the lagoons.

Natura 2000 areas

Natura 2000 areas is the national dataset of natura protected areas used to pick protected lagoons.

3.1 Study area

As data from the whole Finnish coast except Åland were available, the analysis will make use of the whole dataset (Figure 9). The Finnish coastline is very complex and there are differences between the means and rate at which the lagoons in different areas form, but the main classification still applies and this way it is possible to make comparisons between areas and apply the national legislation.

Figure 9: Map of research area

All regions included are presented below to give an overview of the main differences between different areas of the coast.

3.1.1 Bay of Bothnia

Furthest north in the Baltic Sea is the Bay of Bothnia (Figure 10). Land upheaval is very strong, only second largest after the Quark. The lagoons are sparse and typically formed between the moraine ridges in the area. Salinity in the area is very low compared to the rest of the Baltic Sea basins, because of several large rivers having their estuaries in the region and the fact that it's relatively isolated. This affects the species and communities in the local lagoons. Freshwater species are common in the area including the threatened Baltic water-plantain *Alisma wahlenbergii* (Kotilainen et al., 2020) and water pygmy weed *Crassula aquatica*.

Figure 10: Bay of Bothnia

3.1.2 The Quark

Most of the lagoons in Finland can be found in or near the Quark (Figure 11). The reason for this is the strong land upheaval along with the deGeer moraine typical of the region. This type of moraine forms long ridges that form into lagoons very easily. Strong land upheaval can also be a challenge for protection as the need for dredging in the shallow area is great. Salinity is lower than in the Baltic proper, but can sustain species such as the bladderwrack (*Fucus vesiculosus, F. radicans*) and the blue mussel (*Mytilus sp.*) in the southern parts of the area.

Figure 11: The Quark

3.1.3 Bothnian Sea

The main characteristics of the Bothnian Sea (Figure 12) are a strong land upheaval and a steeper coastal profile, compared with other areas of the Gulf of Bothnia. Lagoons in the area can be formed out of rock or boulders as well as softer sediments.

Figure 12: Bothnian Sea

3.1.4 Archipelago Sea

The Archipelago Sea (Figure 13) consists of approximately 40 000 islands. Rocky substrate is common in the area and lagoons typically have rocky shores as opposed to lagoons in northern Gulf of Bothnia. The land upheaval is mediocre, as the area is not ideal for the emergence of lagoons geologically but makes up for it with its long and complex shoreline.

Figure 13: Archipelago Sea

3.1.5 Gulf of Finland

The long stretching Gulf of Finland (Figure 14) varies between its eastern and western parts so much that it could be split into two basins. The western part is comparable with the rest of southern Finland when it comes to land upheaval and salinity, but in the east, land upheaval is the lowest in Finland and the number of lagoons is low. Low salinity in the east is a species defining characteristic.

Figure 14: Gulf of Finland

3.2 Lagoons dataset

Made in the projects TILA2, where the state of marine protection is assessed and TILA3 that did an evaluation of marine habitats in the spring of 2021, the lagoons dataset is a combination of new methods and methods used in the project Kvarken Flada. The old dataset was used as a base and some potential glo-lakes were added before the main classification was made. Addition of glo lakes was done by taking lakes from Finnish land surveys database and overlapping it with a 10% flood risk dataset from the Finnish Environmental agency and Center for Economic Development, Transport, and the Environment. This dataset was then classified with two different sets of aerial photographs from Finnish land survey and ESRI.

The main classification includes the morphology of the lagoon, but also information on the state of the mouth of the lagoon, especially about potential dredging, and modifications. This is vital information when determining the protection status of lagoons. Additional information is also available, like lagoon chain order which can be used when doing calculations about the catchment area and if there is a creek leading to the sea from a potential glo lake. Deletion causes were also marked to keep track of the changes to the old dataset (Table 1).

Table 1: Lagoon classification

Attribute	**Explanation**	**Value and explanation**
Delete	For deleting lagoon figures	0 Keep 1 Delete 2 Check
Deletion cause	Cause of deletion	0 Not deleted 1 Strait or bay 2 Man made 3 Ground obstacle 4 Lake 5 Estuary 6 Dry 7 Overgrown
Morphology	Lagoon classification	1 Juvenile flad 2 Flad 3 Gloflad 4 Glo 5 Glolake 6 Lagoon
Chain	The order of lagoon in a chain, where applicable.	1 Closest to sea 2 2nd in chain 3 3rd in chain
Mouth	Status of the mouth area	0 Modified 1 Not visibly modified 2 Creek or ditch (glo or glolake)

3.2.1 Morphology

The classification of morphology follows the descriptions from interpretation guides and manuals where it is not in conflict with the terminology presented by Munsterhjelm (1997). Classification from aerial images is not as reliable as one done in the field, but it gives a representative picture of the relations between different stages in the development (Figure 15 and 16).

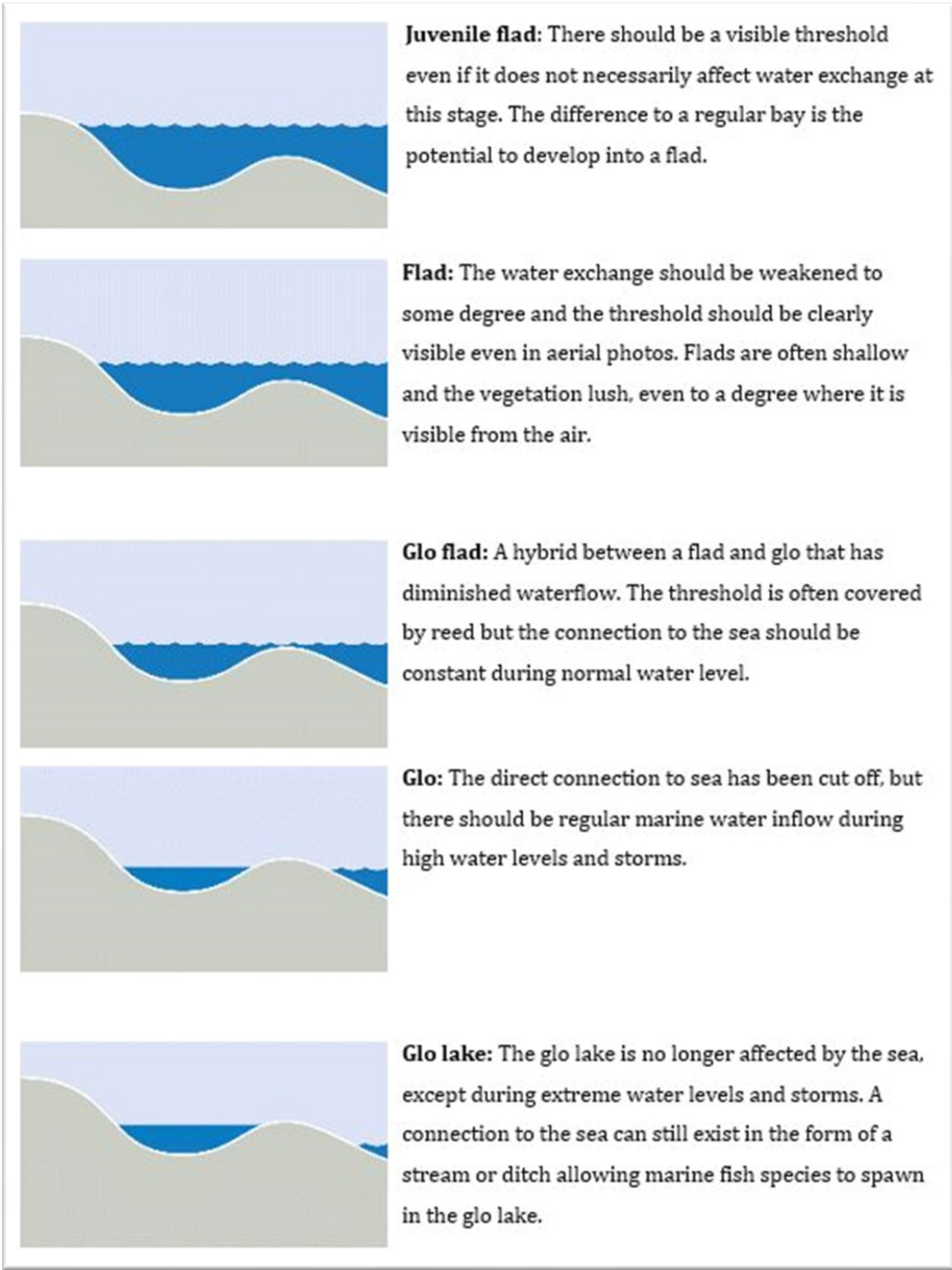

Figure 15: Lagoon development stages and descriptions for the orthophoto classification. Modified from Mikkola et al. (2020).

Lagoon: There are some lagoons that are not part of the flad-glo development series. These types of lagoons do not have a threshold but have their water flow diminished by a strait or islets. They can develop into a glo or even a lake without going through the regular phases of the development (Airaksinen & Karttunen 2001).

In the data the figures classified as lagoons are often large and comprised of several smaller objects in different stages of flad-glo development.

Figure 16: Main development stages from the upper left: Juvenile flad, flad, glo-flad and glo. Photos: ©Jaakko Haapamäki/Metsähallitus

3.2.2 Future development of lagoon data

The current dataset is the best available data, but there are ways to make it better. As lagoons are a constantly changing environment and there are always changes from the natural progression in the flad-glo succession and human induced changes. Therefore, the dataset should be updated regularly to account for these changes. As satellite photos have become more available recently and the use of algorithms more common the automatic classification of coastal ecosystems is also a possibility. The use of machine learning needs good learning data to support it, however, and this dataset is the first step in producing it. In the future the lagoons dataset could be made even better by adding new lagoons to it and correcting the faulty geometrics, that the data currently has.

3.3 Human activities dataset

Comparing with Kvarken Flada, where a similar classification was made, the lagoon dataset has fewer classes of human activities. This is because of the now available human activities dataset, that has the necessary classifications.

The human activities dataset was made as a combined effort of the projects TILA2 and TILA3, SEAmBoth, ECOnnect, and SEAGIS2 using aerial photographs and it includes 115 000 activities that were visible in orthophotos (Figure 17). The activities that are of most interest for this work are dredging activities and piers inside lagoons since they can be used to assess the natural state of the lagoon.

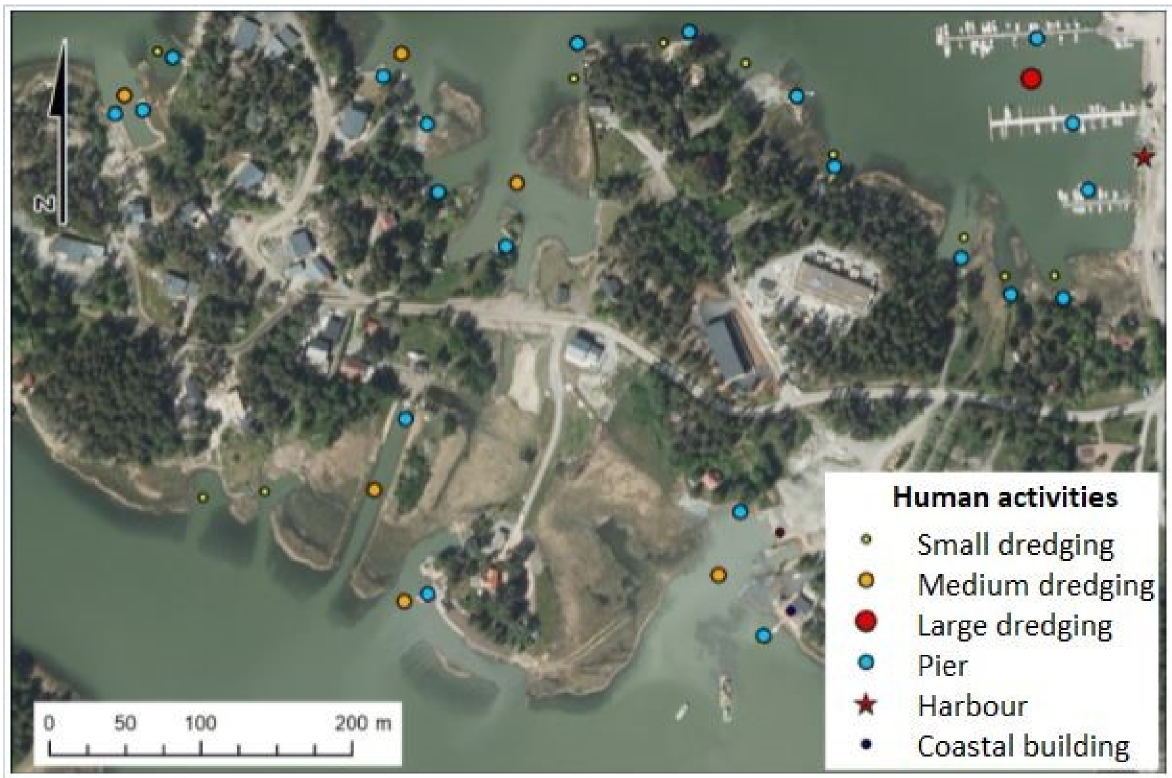

Figure 17: Example of the human activities dataset.

3.4 Protection of coastal lagoons

Lagoons can be protected by the Nature Conservation Act (1096/1996) inside Natura 2000 protected areas or by the Water Act (587/2011). The type of lagoon protected depends on its characteristics. The Nature Conservation Act protects all lagoons inside Natura protected areas, and the Water Act protects all flads, glo-flads, gloes and glo-lakes even if they are not inside nature protected areas, but they must be in a natural condition and have a maximum area of 10 hectares. It should be noted that the water act does not include juvenile flads and that glo-lakes are excluded from the coastal lagoon habitat (Figure 18).

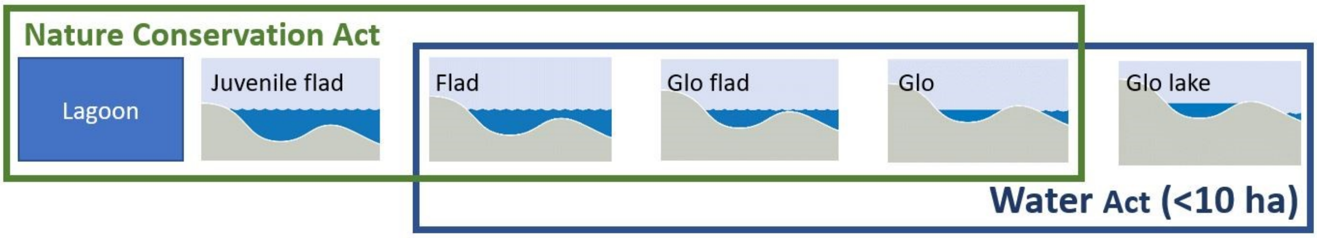

Figure 18: Protection of different classes of lagoons in Finnish legislation

3.5 Determining the protection status

The coastal lagoons -dataset is the base of the classification. The data can be used to assess the probable natural condition of the figures and the development stage they represent. This is crucial in determining protection status of the figures. To determine protection status the Finnish coastal lagoons dataset was used. The dataset includes variables that can be used to pick individual figures that are within the protection of the water act and the Natura protected areas can be used to find figures that are within Natura networks protection (Figure 19).

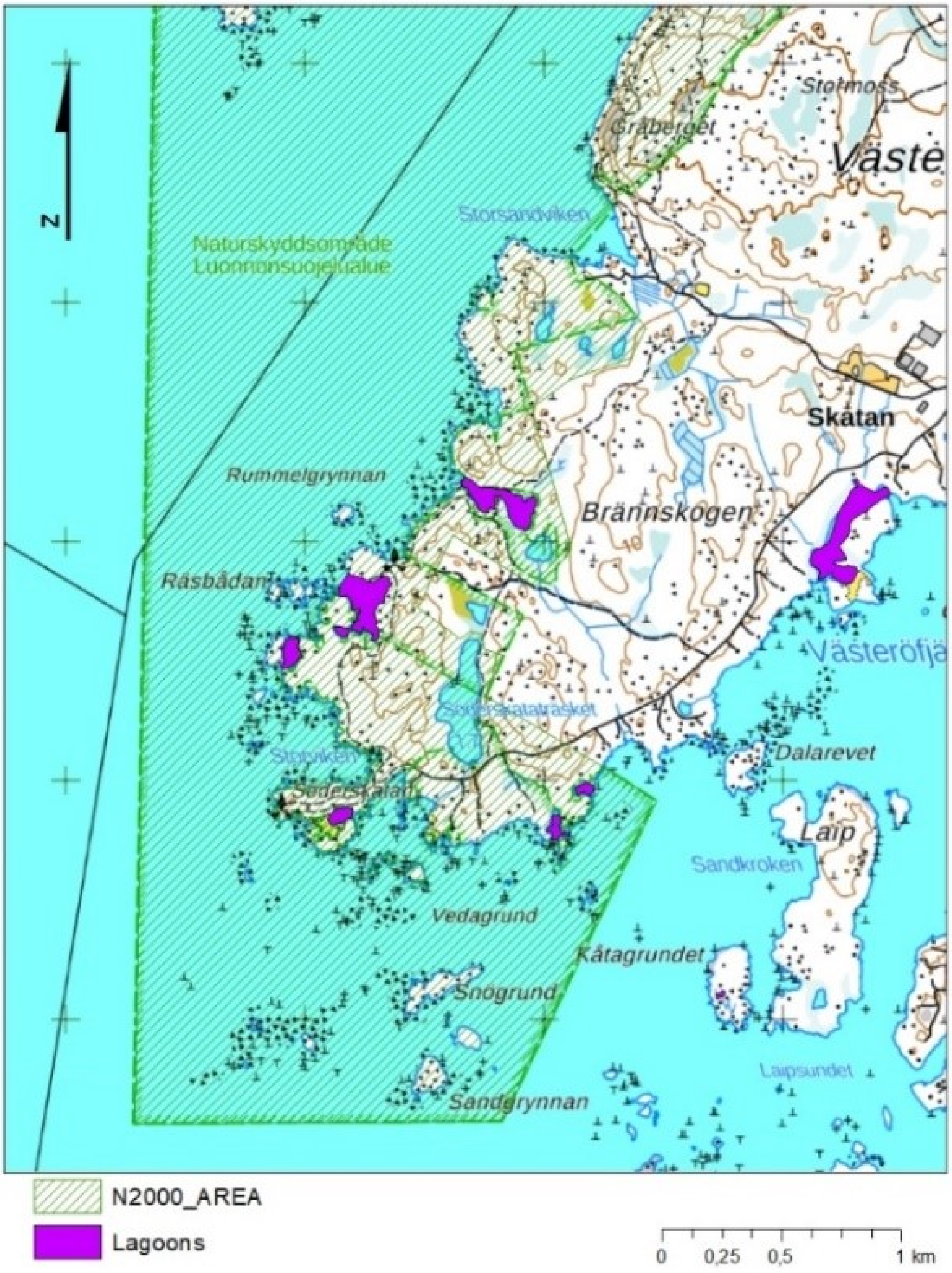

Figure 19: Lagoons and natura protected areas

To detect which of the lagoons are in natural condition and thus protected by the water act, the human activities dataset is used. The dataset includes all dredgings, piers, breakwaters, and small harbours visible in aerial photographs and is therefore very useful in classifying small water objects by anthropogenic pressures.

3.5.1 Assessing natural condition

The condition was determined by using the classification with the human activities data. The lagoon was marked as natural, if there were no dredging activities or piers inside the lagoon and no buildings within 50 m. from the shore. The catchment areas were not analysed but it should be noted that agriculture and forestry can also have effects on the natural condition of the lagoon.

3.5.2 Protection status

Protection status was determined by comparing the data. Lagoons excluding glo lakes inside Natura protected areas were classified as protected by Natura and flads, glo flads, gloes and glo lakes under ten hectares without human activities were classified as protected by the Water Act.

3.5.3 Final classification

The datasets were combined and used for classifying figures by their development stage, protection level and anthropogenic pressures. This classification (Table 2) was used to verify the protection status in relation to human activities.

Table 2: Description of final classification table

Attribute	Explanation	Value and explanation
Morphology	Development stage	1 Juvenile flad 2 Flad 3 Glo-flad 4 Glo 5 Glo-lake 6 Lagoon
Condition	Natural condition	0 Not natural 1 Natural
Protected	Protection status	1 Natura 2 Water Act 3 Both 4 None
Area	Figure area	square meters

4 Results - status of lagoon protection in Finland

Protection status was determined by comparing the classified lagoon dataset with the anthropogenic pressures data and protected areas. A lagoon is considered protected if it is within a Natura 2000 protected area and belongs to a morphology class in the habitat directive or if it fulfils the morphology and size conditions in the Water Act.

Most lagoons in the data (67%) are smaller than one hectare in area, but these only add up to 3% of the total area of lagoons (Figure 20). As small lagoons are not heavily utilized and using the whole dataset would distort the results. All the analyses are therefore conducted excluding the smallest area class of 0-1 hectares.

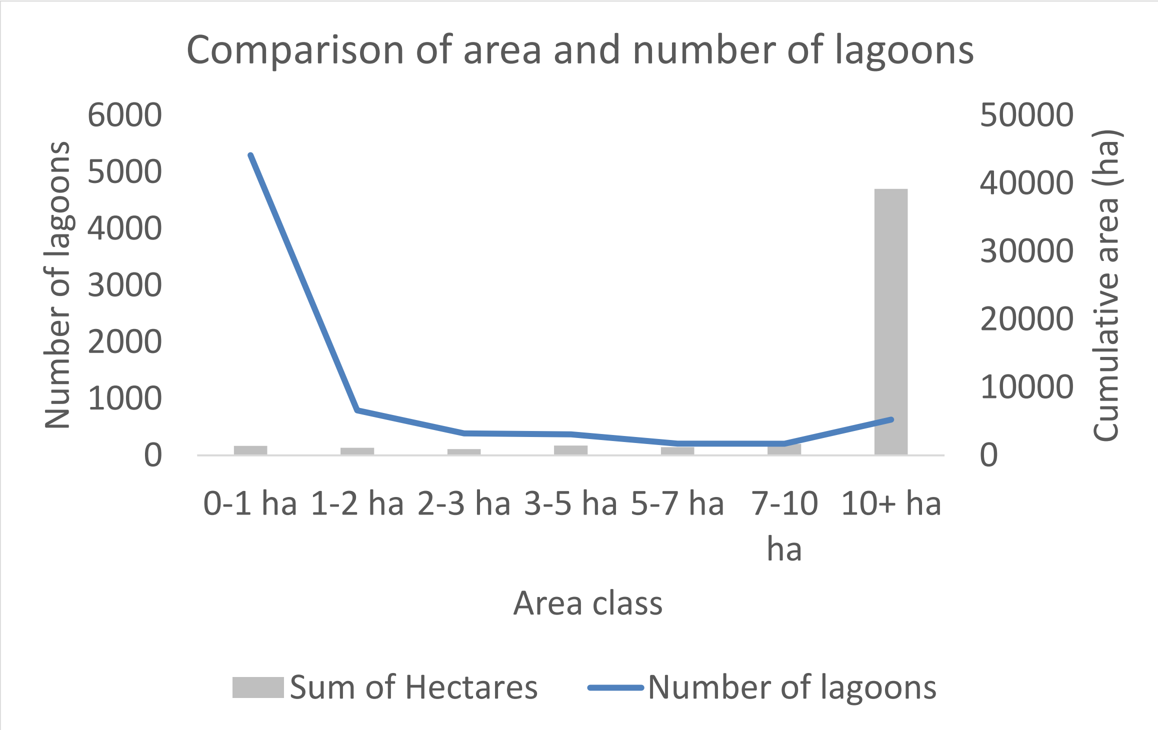

Figure 20: Comparison of cumulative area and number of individual lagoon figures in the dataset

Human activity rises with the size of the lagoon. This can partly be explained by the fact that the larger figures have more potential sites for summer cottages.

Comparing the human pressures by figure area, the larger the figure, the more pressures there are. This method does not account for the extent of the pressures. A large figure with a single pier and a cottage can be very close to natural condition but will still show as under pressure in the data. The clear trend is that the larger lagoons are more likely to be under human impacts. (Figure 21)

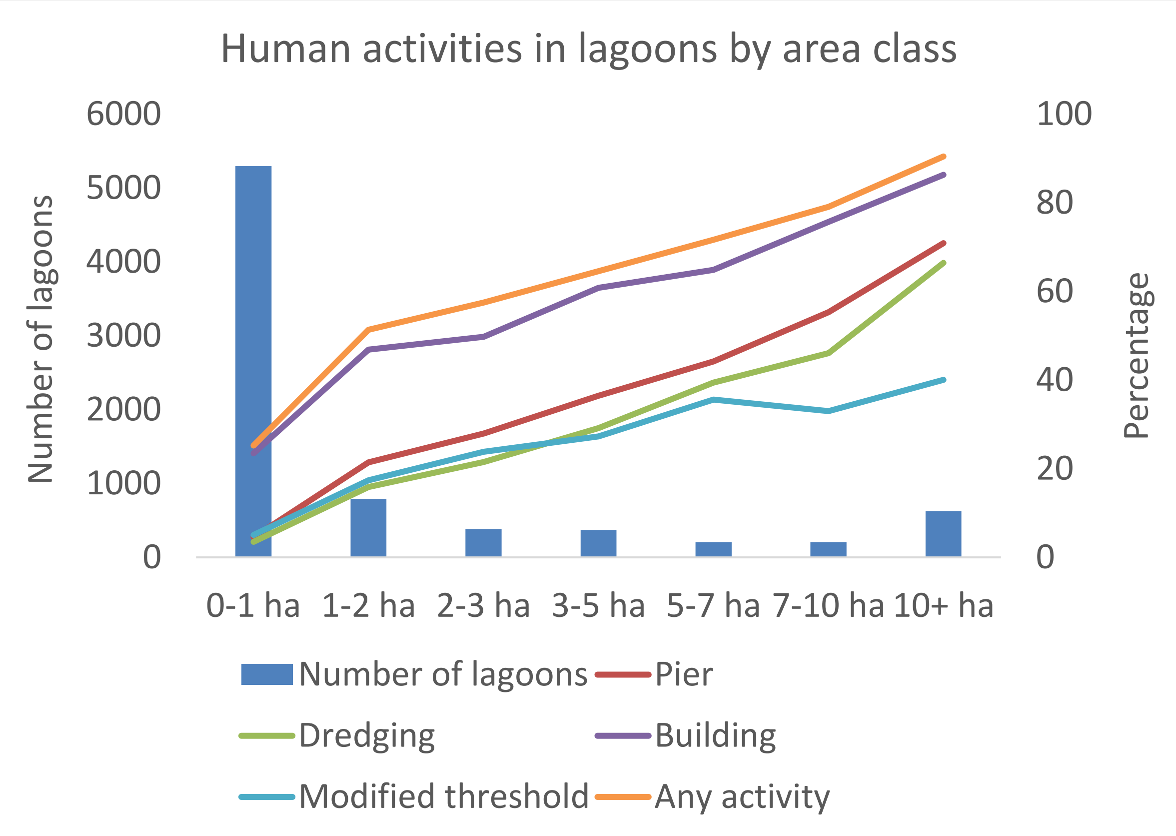

Figure 21: Human activities by area class

Anthropogenic pressures by morphology class vary more in terms of which pressures are most common (Figure 22). The 'lagoon' class is the one under the most human pressure, but this is mainly due to it consisting of mostly large and complex figures, that could be classified into smaller figures of varying development stages. The most dredged development stage is obviously glo flad as it is the stage occurring when the lagoon has recently become isolated, and dredging is probably necessary to maintain access by boat. The second most dredged stages are flads and gloes, with flads having a higher percentage of the dredging activities inside the flad whereas gloes have a higher percentage of dredged thresholds. Glo-lakes are least affected by human activities. The reason for this can be either due to glo lakes being isolated from the sea, their high protection percentage or both combined. Juvenile flads have a high usage percentage with a pier in >50% of the figures, but they also have a lower dredging percentage than later stages.

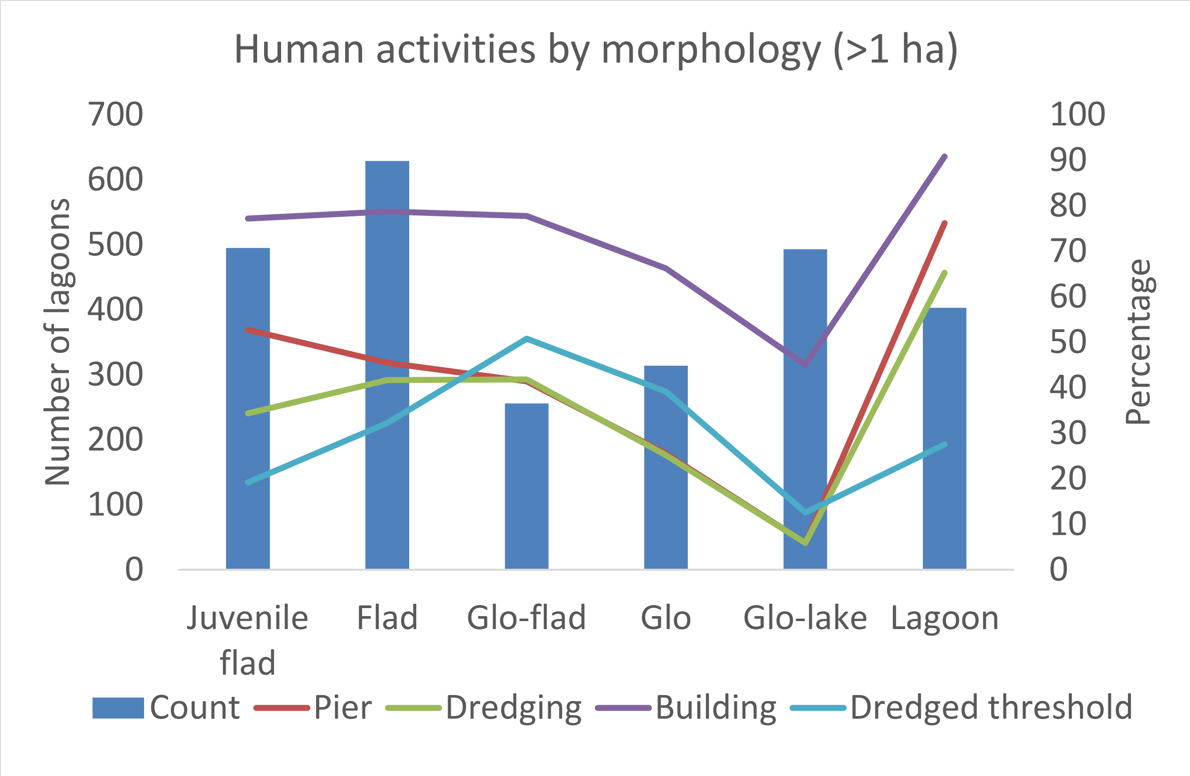

Figure 22: human activities by morphology

Since the areas between lagoons and development stages vary, it is interesting to compare if activities per area yields different results. The differences between stages seem to be even more dramatic, as juvenile flads and flads have over 0,7 activities per hectare, the number drops to 0,5 for gloflads, 0,2 for gloes and 0,02 for glolakes (Figure 23).

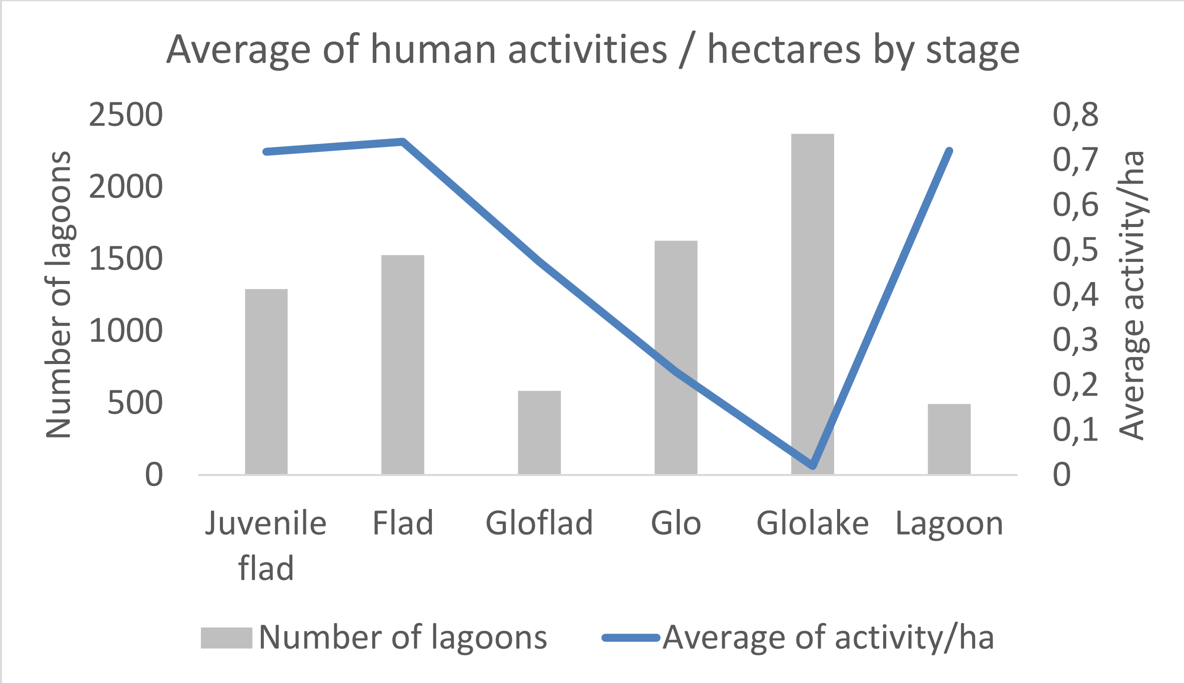

Figure 23: human activities / hectares by development stage

Looking at the number of protected lagoons, it is clear that glo lakes are the most protected class (57% protected), even though they are not part of the Natura habitat. Both flads (46% protected) and gloes (50% protected) rise to a decent protection level, but juvenile flads remain at a low level (26% protected) as they are not included in the phrasing of the Water act (Figure 24).

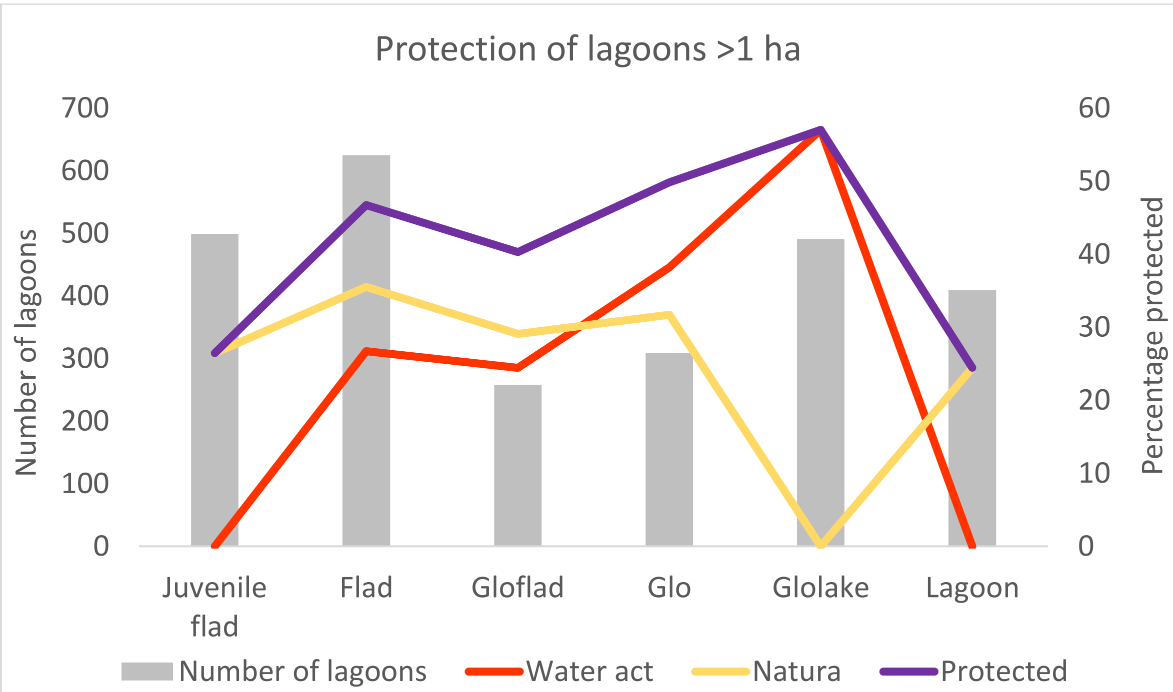

Figure 24: Protection percentage of lagoons by development stage

5 Discussion

Lagoons are an ecological hotspot that house many endangered species and habitats. Even the more common vegetation communities found in lagoons have a great significance for invertebrates, birds and production of many ecosystem services, such as nutrients and carbon dioxide binding and recreational benefits (Ilvessalo-Lax & Mikkola, 2019). Most of the lagoons that are in natural condition are protected by the water act even outside protected areas and as a Natura habitat the rest are protected by the Nature Conservation act inside Natura protected areas. Still, 28% of all lagoons larger than one hectare have a modified threshold and 41% have at least one pier inside them. Almost 70% of all lagoons are in some way altered by human activities and this does not include pressures from the catchment area such as nutrient and particle loads from agriculture or forestry.

The low protection level can in part be due to the wording of the Water act as the law has a size limit of 10 hectares and does not include juvenile flads. As lagoons can be notoriously difficult to delimit and larger lagoons of especially the earlier development stages are usually in fact comprised of several smaller lagoon figures, that have not yet completely separated from each other, it is hard to give an accurate estimate of a lagoon objects size. As the larger lagoons and juvenile flads are outside the legislations wording, they can in many cases be exploited freely and are therefore not protected anymore if they reach a stage where they otherwise would fulfill the conditions.

Another reason for low protection levels could be the legislation concerning dredging activities. In Finland one is required to notify the authorities about a dredging of under 500 m^3. A larger dredging always requires a permit. In practice there are more small dredging activities than there are notifications made and the effects of multiple small dredging activities can be quite dramatic locally (Kotilainen et al., 2020). A dredged lagoon is no longer protected by the Water act, so the practice can influence the level of protection even after juvenile flads develop into a flads.

When inspecting the data, the classes that are the least protected are juvenile flads and lagoons. In the case of lagoons, the reason could be that they are often figures consisting of several smaller objects and are outside the conditions of the Water Act because they are often larger than 10 hectares. Concerning juvenile flads they are not protected by the Water Act and the coverage of protected areas is not enough in itself to reach a good level.

There are several problems that stem from the wording of the water act as it uses the terms ‘flads and glo-lakes’. This can be interpreted as only flads and gloes, only flads and glo-lakes or all development stages between flads and glo-lakes. The latter interpretation is the most commonly used. Common to all interpretations is that juvenile flads are not a part of the classification. Another problem is that the law only concerns lagoon objects in natural condition. This leads to the fact that all pressure classes that affect the lagoon can basically dissolve its protection status even in later development stages. Lastly the size limit of 10 hectares can be problematic, as to delimit larger lagoons can often be difficult and an object of over 10 hectares could often be separated into smaller individual lagoons that would be under the area limit.

The terminology concerning lagoons is a large problem as the terms describing development stages are used liberally and there are several different interpretations. It would be beneficial to refrain from using the terms individually in legislation, manuals and guides concerning the management of lagoons. It should always be clear if the author means a certain development stage, several stages or the whole development series and the best way to achieve this is by referencing the classification in Munsterhjelm (1997) as it has descriptions of the stages and names in Finnish, Swedish and English.

The wording of the Water Act is problematic as it is unclear what constitutes a lagoon in natural condition. Considering eutrophication alone, there may not be any areas left in natural condition on the Finnish coast. The wording in Nature Conservation Act (1096/1996) concerning natura habitats is clearer as it prohibits the modification of the habitat when it jeopardizes its characteristic features.

The dredging activities are a big threat to lagoons and especially dredging of the threshold (Saarinen, 2019). This is in part due to the large number of small dredging activities found on the coast, ignorance concerning the consequences a dredging in the threshold can have on the whole lagoon and the fact that modified lagoons are not protected by the Water Act. A swimming pier or small dredging does not necessarily threaten the functionality of the lagoon, but a dredging in the threshold almost certainly will. Distinguishing between the effects that different actions have would be important when managing lagoons.

5.1 Management of lagoons

Protection of lagoons is important, but it is only one tool in the management of coastal lagoons. As protection mainly consists of restrictions it is not always the most efficient way to achieve the best results for the environment.

Taking the ecosystem services into account can be beneficial in management of lagoons. Cultural services that produce anthropogenic pressures could be a threat to provisional and regulating services (Ilvessalo-Lax & Mikkola, 2019), but it should be remembered that the latter ones are a pre-requisite for the former. Cultural services can and should be realised in a way that disturbs the provisional and regulating services as little as possible but there should be areas that enable all these different types of services individually.

Another important tool for management is increasing awareness concerning lagoon environments and the benefits that a well-functioning lagoon provides. Lagoon functions are often disturbed and whole systems even destroyed because it is thought that opening a threshold and dredging the lagoon will lead to better water quality, when it in fact will lead to the opposite. In later development stages a dredged threshold in addition to strong land uplift can lead to a dramatic lowering of water levels (Saarinen, 2019). This is seldom a desired effect.

In less dramatic cases of human induced destruction the function of a lagoon can be restored. The actions that are currently available include repairing thresholds by making them narrower or wider, actions in the catchment area like restoring wetlands to diminish emissions to the lagoon and even planting submerged vegetation in the lagoon (Saarinen, 2019). These restauration actions can be quite costly, but in many cases, worth the expense.

The most efficient way to manage lagoons makes use of all the tools described: Protection, increasing awareness and restoration and considering the provided ecosystem services are important to ensure a well-functioning coastal ecosystem as well as a lively coastal area.

5.2 Uncertainties and applicability of results

The analysis was done using the best available data. That being said, the data could always be better. The lagoon data currently has some faulty geometrics, that could not be fixed with the resources available. In the future corrections to the dataset should be made by fixing the geometrics, adding more lagoons and splitting the lagoons that currently consist of many individual pools. This new dataset could then be used to do further analyses in catchment areas to make a more in-depth analysis on the human activities. In the future more resources should be directed towards producing spatial vegetation data inside lagoons to find the most valuable lagoons and to be able to analyse the impacts of different human activities have in lagoons. The new data should also advance the use of satellite images and machine learning to make tracking changes in lagoon environments more efficient.

The analyses done in my thesis were rather simple and more could have been done concerning vegetation in the lagoons, as vegetation data is available. Also, the human activities could have been classified more in detail and their collective impacts considered. Still, the aims of this thesis were fulfilled, as it identifies the early juvenile flads as the most vulnerable development stage and there is now information available about the level of protection of the different development stages of coastal lagoons. This information can in the future be used to plan further analysis, research, management of protection and restauration targets, but further improvements can open even more possibilities.

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