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A GIS tool for biological research
- visualising flycatcher breeding data collected on Öland

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Abstract

This thesis describes the development of an interactive map application that visualises geographical and biological data for a research project about flycatchers. Biologists from Uppsala University study the interaction between two different species of flycatchers on Öland. A big need for new field maps was discovered, which led to the idea of creating an interactive map application. Nest boxes on Öland were positioned using GPS and digital maps were acquired from the Digital Map Library. A web application prototype was created, combining nest box positions with collected data about the birds.

Semi-structured interviews were held with the biologists. The software development method of evolutionary prototyping was used together with UMN MapServer development environment. User tests were conducted, including a heuristic usability evaluation.

The resulting application will be used by the biologists for educational purposes and illustrating scientific articles and presentations.

Summary in Swedish

Den här uppsatsen beskriver utvecklingen av en interaktiv kartapplikation, som visualiserar geografiska och biologiska data i ett forskningsprojekt om flugsnappare. Biologer från Uppsala universitet studerar interaktionen mellan två olika arter av flugsnappare på Öland. Ett stort behov av nya fältkartor upptäcktes, vilket ledde till idén att utveckla en interaktiv kartapplikation. Fågelholkar på Öland positionerades med hjälp av GPS och digitala kartor anskaffades från Digitala Kartbiblioteket. En prototyp gjordes på en webbapplikation som kombinerade fågelholkars positioner med insamlade fågeldata.

Semistrukturerade intervjuer hölls med biologerna. Evolutionär prototyping användes som utvecklingsmetod, tillsammans med UMN Mapservers utvecklingsmiljö. Det gjordes också användartester, inklusive en heuristisk utvärdering av användbarheten.

Resultatet blev en applikation som biologerna kommer att använda i utbildningssyfte samt för illustrationer i vetenskapliga artiklar och presentationer.

Acknowledgements

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1. Introduction

Despite the wide range of computer-aided tools, many scientists still don't take full advantage of the powerful technology available today. This is especially true in the field of green biology, which lies far away from computer science. In my experience, many green biologists are reluctant to use computers more than necessary while most computer scientists are totally uninterested in green biology. This gap between computer science and green biology makes combinations of the two both more challenging, as well as more rewarding, than combinations of other, more closely related sciences. Biologists have a lot to benefit from enhanced computer systems, something this thesis aims to prove.

1.1 Problem background

Every spring hundreds of flycatchers arrive on Öland to breed. Anna Qvarnström, assistant professor at the Department of Ecology and Evolution, Uppsala University, studies the interaction between two different species of flycatchers. For several years she and her colleagues have been monitoring the populations on Öland.

Originally my thesis was meant to be about testing wireless sensor networks for monitoring temperatures in nest boxes. However, the sensors turned out to function poorly and at the same time I discovered a big need among the biologists for new field maps. This led to the idea of creating an interactive map application that would visualise not only the placements of the nest boxes, but also include information about the birds that are breeding inside these boxes.

1.2 Purpose

The purpose of this thesis will be to describe the development of a system prototype that visualises geographical and biological data for a research project about flycatchers.

1.3 Method

The application project will be implemented as a software project; including planning, analysing, designing and implementing a software application. Semi-structured interviews will be held with the biology researchers, which means the use of both pre-prepared questions and exploring new arising topics (Benyon, Turner and Turner 2005, p. 216). This is necessary because I don't have enough background knowledge of the subject for a structured interview including only pre-prepared questions. At the same time, an unstructured interview without pre-prepared issues to discuss may result in a vast amount of information of no practical use to the application development.

Necessary geographical data will be collected and then the application will be developed through evolutionary prototyping and documented on paper. According to Vliet (2004), evolutionary prototyping means that the user starts by formulating raw requirements and then the developers work on a prototype that evolves, together with new or changed requirements, into a final product after a number of iterations. I have chosen evolutionary prototyping partly

because of the limited familiarity with GIS-applications for both myself and the biologists. A concrete prototype will simplify our communication and I believe it will clarify requirements more quickly. For simplicity, the prototype will be implemented as a web application.

A usability evaluation will also be conducted by a number of experts, using Jakob Nielsen's (23/8-2007) ten heuristics for good user interface design. The result will be used to improve the application interface.

1.4 Delimitations

The flycatcher project has 20 years of collected data available. Naturally only a subset of that data will be used in this project and thesis, as an example. I will only include a few of the nest box areas on Öland that have been positioned with GPS. Emphasis will be on the two flycatcher species pied flycatcher and collared flycatcher. For economic reasons I will, as far as possible, use software that are free or already available to me. That means that not always the most optimal existing software or technology for the purpose will be utilised. Built-in software features impose limitations on the development and might complicate realisation of requirements. By choosing evolutionary prototyping, I hope to avoid modeling requirements that prove impossible to implement in the final application because of constraints in the development environment.

1.5 Outline of the thesis

Chapter two will give some background information about geographical information systems and chapter three about flycatchers and the flycatcher research project. The project setup will be presented in chapter four explaining necessary preparations before developing the prototype. The actual creation of the application will then be described in chapter five together with screenshots and results from user tests. A conclusion and discussion will be presented in chapter six and a glossary with clarifications in both English and Swedish will be found in Appendix 1.

2. Geographical Information System

This chapter gives an introduction to Geographical Information Systems, GIS, and the two storage formats; raster and vector. It also explains the fundamentals of a Global Positioning System, GPS.

2.1 Background

A Geographical Information System is a computerised system for storage, access, manipulation, analysis and presentation of geographical reference data (Hall, Alm, Ene and Jansson 2003, p. 131). The development of GIS started in the 1960s, when it was possible to make computerised analyses of geographical objects (Eklundh 2003, pp. 14-15). Today GIS are becoming more and more popular in a wide range of areas, from navigation systems in cars to three dimensional atlas applications on the World Wide Web such as Google Earth.

By overloading different map layers, new relations can be found and analysed (Eklundh 2003, p. 23). One example could be to take a map showing streets of a city and overload it with a layer showing population density, in order to calculate the most optimal placements for bus stops.

2.2 GIS formats

There are mainly two conceptual storage formats of geographical data, raster and vector (Eklundh and Pilesjö, 2003, pp. 96-111). The following paragraphs will explain both.

2.2.1 Raster

Raster format means that you use a grid to represent the geographical area (*ibid.*). Each cell in the grid has a value that translates to some information about the map. For example, 1 can represent water, 2 can represent forest and 3 can represent field (Figure 1). How detailed the raster representation is depends on the resolution. Many small grid cells hold more information than a few large grid cells covering the same area. Of course, more cells also means bigger storage size.

Figure 1. A map (left) transforms into a raster (right), where 1 represents water, 2 forest and 3 field. (Image by the author)

It is not always clear which value best represents the raster cell. Two common ways of choosing a value is to choose the information type covering the biggest part of the cell area or the information type of the absolute middle of the cell. Usually each cell only holds data about one attribute, like vegetation type, altitude or inhabitants. Therefore, each attribute needs its own raster layer of grid cells.

2.2.2 Vector format

The other conceptual storage format of geographical data, vector format, is built up in an entirely different way. Objects in vector format are represented by points, lines and polygons (*ibid.*). A point is stored as a coordinate in a map with a link to an attribute table. Usually the point has an x-coordinate, a y-coordinate and an ID number. The ID number can be linked to attribute data describing the object, for example type of vegetation. A line consists of two or more points, where the first point marks the beginning of the line and the last point the end of the line. Similarly, a polygon is a surface built up of four or more points, where the first point and the last point are identical and therefore means closure. Figure 2 shows a field represented by one geographical file with its border coordinates (file A) connected to another file with attribute data (file B) via an ID "F1".
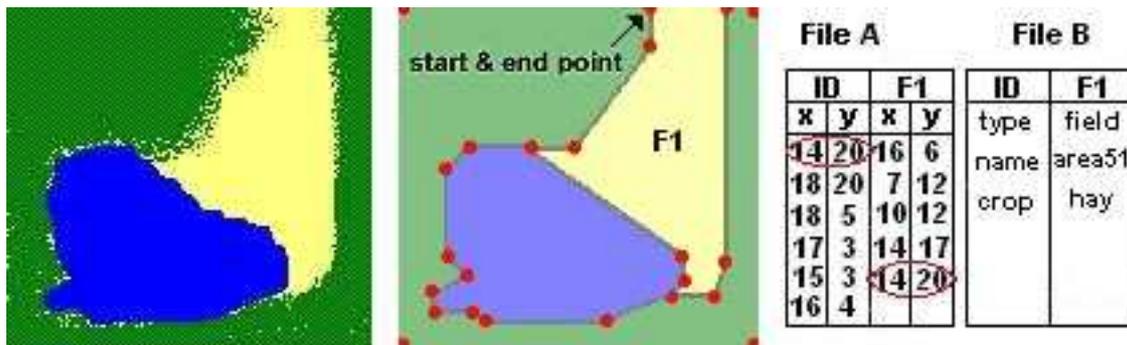
Figure 2. A field on a map (left) undergoes a vector transformation (right). Start and end point is the same. (Image by the author)

As shown in Figure 2 above, the real map to the left is more detailed than the map transformed into vector format to the right. This method to simplify a map is called generalisation. How detailed a vector representation is depends on its degree of generalisation. A highly detailed map in vector format is built up by an extensive number of points, all stored as coordinates in a file. Hence, the level of detail in a map stored in vector format depends on storage capacity, similarly to raster format.

2.2.3 Which format is better?

Both raster and vector formats have their strengths and drawbacks. According to Eklundh and Pilesjö (2003, p. 112), raster has a big advantage when it comes to storing homogeneous objects and continuous surfaces, such as aerial photos or satellite photos. The raster cells are closely connected with their neighbour cells and the fact that all cells are equal in size

facilitates logical and mathematical operations as well as advanced analyses of spatial relations like proximity. A search for neighbouring objects in a vector map takes much longer than finding neighbouring cells in a raster map.

The vector structure on the other hand is usually more geometrically precise and the storage format is more compact. Because they are built up in an object-oriented fashion, vector maps are also better for operations on multiple attributes, unlike raster maps that have one attribute per layer.

So, if the task is to handle multiple attributes or make operations on very precise coordinates, then vector format is preferred. If the task is to work with continuous surfaces or study the interaction within or between different layers of data, then raster format is preferred.

2.3 Global Positioning System

The following paragraphs explain how the Global Positioning System, GPS, works and ends with a brief part about the Galileo Positioning System.

2.3.1 How GPS works

"A GIS without data is - like other sorts of information - useless" (Hauska 2003, p. 149). Using the Global Positioning System, GPS, is one way to collect geographical data to a GIS. The American satellite navigation system NAVSTAR GPS is based on a minimum of 24 satellites that orbit the earth (Hall *et al*. 2003, p. 157). Each satellite has four atomic clocks and periodically generates a signal that is sent out, together with the satellite's current position (Garmin.com, 9/5-2006). The system is controlled and synchronised by five ground stations placed around the equator (Hauska 2003, p. 154).

A GPS receiver generates an identical signal at the same time as the satellites. By measuring the time difference between the receiver's own generation of the signal and the arrival of a satellite signal, it is possible to calculate how far away the satellite is using the formula `d=t*v` where `d` stands for distance, `t` for time and `v` for velocity (Kunskap och fakta, 28/5-2006). Time is the time difference of the signals and velocity is 300000 km/s, since radio waves travel at the speed of light. Signals from at least four satellites are needed for the GPS receiver to calculate its own three dimensional position in latitude, longitude and altitude (Garmin.com, 9/5-2006).

2.3.2 Trilateration

The calculation method used to get the three dimensional position for the GPS is called trilateration (Wikipedia, 28/5-2006). A two dimensional example is used here for explanation. If the distance to one satellite is known, the possible positions of the receiver can be in any direction from the satellite, on a circle around the satellite (Figure 3). If the distance to two satellites is known, the receiver's position must be in one of the two intersection points of the two circles (Figure 4). A third known satellite distance gives an absolute position of the GPS receiver (Figure 5), in a two dimensional picture.
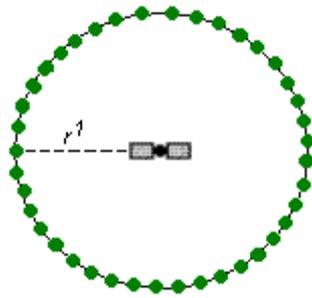
Figure 3. One satellite in a two dimensional picture. The receiver is on a distance r1 from the satellite and the dots indicate possible positions. (Image by the author)
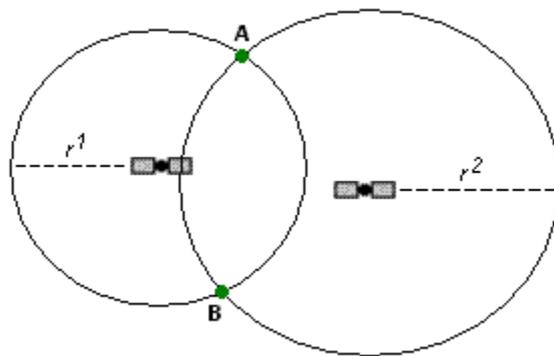
Figure 4. Two satellites in a two dimensional picture. With known distances r1 and r2 to two satellites, the receiver must be found at either A or B. (Image by the author)
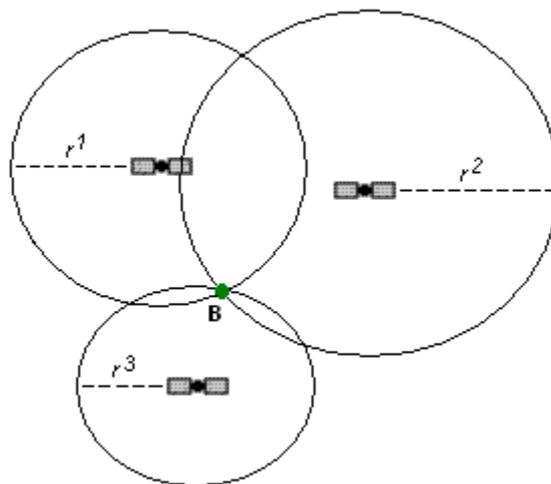
Figure 5. Three satellites in a two dimensional picture. With known distances r1, r2 and r3 to three satellites, the receiver's position can only be in B. (Image by the author)

Since our world is however three dimensional, we need a fourth known satellite distance. In a three dimensional picture with two known satellite positions, the GPS receiver's position can not only be in the upper or lower intersections of the radii, as in a two dimensional picture (Figure 4) but in any direction (Figure 6). The possible receiver positions form a circle where the two radii from the signal spheres meet. Adding a third satellite (Figure 7) to the three dimensional picture will narrow possible receiver positions down to two points where all three spheres intersect.
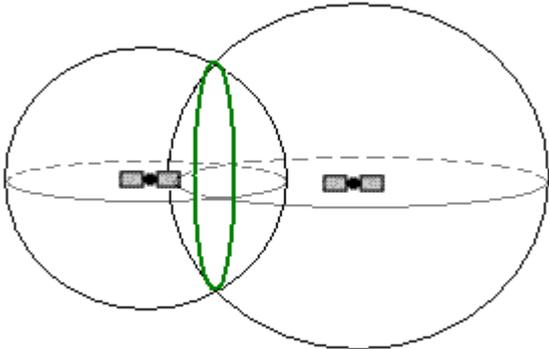
Figure 6. Two satellites, in a three dimensional picture. The GPS receiver's position can be anywhere where the surfaces of the two spheres intersect. (Image by the author)
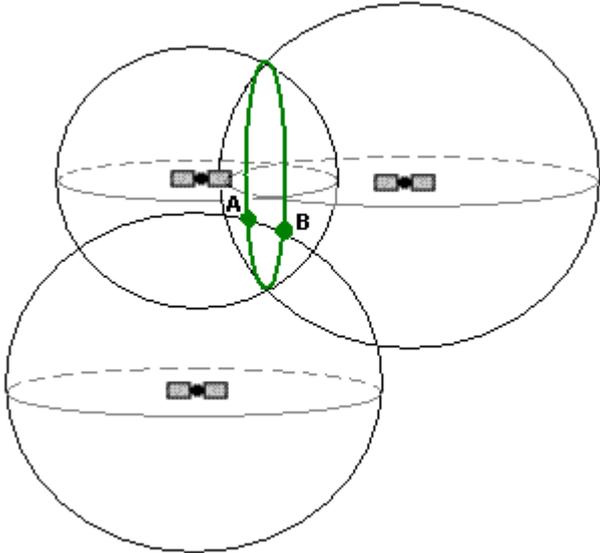
Figure 7. Three satellites in a three dimensional picture. With three satellite positions known, the GPS receiver's position is either A or B. (Image by the author)

It is now clear that three satellites are not enough to pinpoint a GPS receiver's exact location. That is why at least four satellites are needed. Contact with more than four satellites generates an even higher position accuracy (Garmin.com, 9/5-2006).

2.3.3 Accuracy

The accuracy of the calculated position depends on the quality of the receiver and the quality of the satellite data and links. Objects blocking the satellite signals, such as buildings or dense foliage, can make it harder to get a fixed position and a receiver's built-in clock is never as precise as the satellites four atomic clocks (Garmin.com, 9/5-2006). A normal GPS receiver is accurate down to 5-15 meters (Hall *et al*. 2003, p.157).

Hauska (2003, pp. 154-155) also mentions another kind of GPS measurement called Differential GPS, or DGPS, which uses permanent reference stations on the ground as well as the satellites. In Sweden there is a network of such reference stations called the Swedish Network of Permanent Reference Stations, SWEPOS. Today SWEPOS has 74 stations distributed over Sweden (SWEPOS, 28/5-2006). The stations register satellite data and correct it, before sending it out over radio. A license is needed to access and use the data. In 95% of all cases, the measurement accuracy with this method is less than two meters (Hauska 2003, pp. 154-155).

2.3.4 A European satellite system

The European Union is building its own satellite navigation system, the Galileo Positioning System, as an alternative to the American system NAVSTAR GPS. According to Wikipedia (28/5-2006), the system will be operational by year 2010 and offers several advantages over NAVSTAR GPS. For example, users will get greater precision than is currently available and regions at higher latitudes such as Scandinavia will get improved coverage of satellite signals. This means that in a couple of years from now, it may be a good idea to take new GPS positions with better accuracy.

2.4 Maps and GIS software

To visualise the GPS positions, maps in digital form are needed. Lantmäteriet provides students and employees at Swedish universities access to a web service, called the Digital Map Library, where users can download digital maps over Sweden.

There are several GIS applications to choose from, in order to process the digital map data. ESRI Sweden (Environmental Systems Research Institute) and MapInfo Corporation are two of the worlds biggest GIS software companies, both with their own file formats. Converting between different formats is definitely the number one problem when using GIS (Hårdén, 2005). Maps come in a wide range of formats with reference to ellipsoids, map projections and coordinate systems and transformations take a lot of time and energy.

3. Flycatcher research

In this chapter, an introduction to basic concepts as speciation, fitness and natural selection is given, as well as general information about flycatchers and the flycatcher project at Uppsala University.

3.1 Speciation and fitness

The following paragraphs explain the species concept, reproductive barriers, fitness and how speciation occurs by natural selection.

3.1.1 Reproductive barriers

To understand how new species develop, one must begin by defining what constitutes a species. Campbell and Reece (2002, p. 465) use the following definition of a species:
"The biological species concept defines a species as a population or group of populations whose members have the potential to interbreed with one another in nature to produce viable, fertile offspring. In other words, a biological species is the largest set of populations in which genetic exchange is possible and that is genetically isolated from other such populations".

There are many different factors that can genetically isolate populations from each other. These factors are divided into two main groups: prezygotic barriers and postzygotic barriers (*ibid.*, pp. 465-467).

Prezygotic barriers are factors that impede mating or hinder fertilization of the ovum. Examples of such factors are habitat isolation, behavioural isolation and mechanical isolation. Habitat isolation means that two species live in different habitats. They might be geographically isolated or they may live in the same geographical area, but prefer different environments, like woods, swamps or open land. Behavioural isolation is usually connected with courtship rituals. According to Campbell and Reece, species' specific signals that attract mates are probably the most important reproductive barriers for closely related animals. Acoustic differences in song can enable birds to recognise individuals of their own species. Mechanical isolation means that two species are anatomically incompatible.

Postzygotic barriers are barriers that occur after the fertilization of the ovum and prevent the hybrid zygote to grow up into a viable, fertile offspring. Examples of such factors are reduced hybrid viability, reduced hybrid fertility and hybrid breakdown. Reduced hybrid viability means that the hybrid zygote of two species may fail to develop, or if it develops it may never reach sexual maturity. Reduced hybrid fertility means that the hybrid is completely or partly sterile. The mule is such an example. It is a sterile crossbreed between a horse and a donkey. Hybrid breakdown occurs when the hybrids themselves are viable and fertile, but their offspring has reduced viability or fertility.

3.1.2 Origin of species

Speciation is the origin of new species. It is generally divided into two modes, allopatric speciation and sympatric speciation (*ibid.*, pp. 468-475). Allopatric speciation means that a new species emerge from a parent species by the interruption of gene flow between two populations due to geographical separation. If the two populations cannot interbreed again after a long time apart, they have evolved into two different species.

Sympatric speciation occurs within the range of a parent population. Duplication of the genome is one example common in plants, where accidents in cell division cause extra sets of chromosomes. Among animals, sympatric speciation can occur when a subset of a population switches to a different food source or habitat and by doing that isolates itself from the main population. Differences in male appearance can also cause females to develop a preference for a certain type of male.

3.1.3 Fitness and natural selection

There are several definitions of fitness. Campbell and Reece (2002, p. 457) state two:
"Darwinian fitness is the contribution an individual makes to the gene pool of the next generation relative to the contributions of other individuals. In a more quantitative approach to natural selection, population geneticists define relative fitness as the contribution of a genotype to the next generation compared to the contribution of alternative genotypes for the same locus."

A genotype is the set of genes that an organism has, while a locus is a particular place on a chromosome where a certain gene is located. The relative definition is a more exact approach, with focus on the actual genes instead of the individuals as in the Darwinian definition. For example, two people might have the same gene for eye colour. Then it doesn't matter which one of them who transfers the gene to the next generation, because the result is the same.

Natural selection is a process that occurs through individual survival and reproduction success. Individuals who survive and produce high amounts of offspring are said to have a high fitness (Ulfstrand 20/10-2006). Because all populations are exposed to natural selection they will change over time and it is those changes that make populations diverge from each other. Hence there is a close connection between fitness and natural selection.

3.2 Flycatchers

In Sweden, there are four different species of flycatchers: pied flycatcher *Ficedula hypoleuca*, collared flycatcher *F. albicollis*, the red-breasted flycatcher *F. parva* and the spotted flycatcher *Muscicapa striata* (Jonsson 1993). Both the pied flycatcher and the collared flycatcher are found on Öland. The two species are closely related and the fact that they sometimes interbreed has made them interesting research subjects for biologists.

The pied flycatcher (Figure 8) is wide spread in Sweden and the most common flycatcher species found here. The collared flycatcher (Figure 9) on the other hand can in Sweden only

be found on Gotland and Öland. It probably colonised the Baltic islands from Central Europe (Interview with Qvarnström and Wiley 6/3-2006).

Anna Qvarnström, assistant professor, Christopher Wiley, PhD student, and Nina Svedin, PhD student, at the Department of Ecology and Evolution, Uppsala University, have been working several years with collared flycatchers and pied flycatchers. Every summer they monitor the flycatchers breeding on Öland, where both species are present. Contrary to many other bird species, the flycatchers are not very sensitive to disturbance. Occasional visits by humans will not make birds abandon their nests. This makes the flycatchers ideal research subjects (Interview with Qvarnström and Wiley 10/2-2006). Both species come to Sweden in May to nest and raise their offspring. They normally lay five to seven eggs that hatch after two weeks (Interview with Qvarnström, Wiley and Svedin 15/3-2006). As the name suggests, flycatchers catch much of their food in the air. Examples of their prey are flies and wasps. Moreover, they mostly feed their chicks with larva. Flycatchers are masters of flying and commonly win air battles with other birds such as tits, due to their superior flying abilities (Interview with Qvarnström and Wiley 6/3-2006). In August they fly south again to spend the rest of the year at a warmer place, like tropical parts of Africa. Pied flycatchers usually live only around one and a half year (Dahlfors, 9/5-2006).

Figure 8. Male pied flycatcher. (Image by the author)

Figure 9. Male collared flycatchers. (Image by the author)

The two species are quite similar in their black and white appearance. However, the male collared flycatcher has, as implied by its name, a white collar shaped marking around its neck and several other white patches that are much smaller in the male pied flycatchers. As with many bird species, the female has a more camouflaging colour of brown. The pied flycatcher and the collared flycatcher also have different songs.

According to Anna Qvarnström and Christopher Wiley (Interview with Qvarnström and Wiley 6/3-2006) there are other pronounced differences between the two species. The collared flycatcher is more aggressive than the pied flycatcher and when the two species compete over the same resources in an area, the collared flycatcher often has the advantage. There also seems to be a tendency that when conditions are good, collared flycatchers can exploit resources much more efficiently than pied flycatchers. On the other hand pied flycatchers seem to be more stable and do better during worse conditions, like low availability on food, than do collared flycatchers. Fluctuations in environmental conditions help the two species to coexist.

Collared flycatchers and pied flycatchers can actually interbreed with each other. The offspring is intermediate between the two species and show a mix of traits from both regarding appearance and song. However, the female hybrid is often sterile while the male hybrid is often fertile.

3.3 Research in Uppsala

The following paragraphs give a short insight into the flycatcher research at Uppsala University, from past to present. There are also a few samples of interesting research findings.

3.3.1 History

Back in 1980, Lars Gustafsson, professor at the Department of Ecology and Evolution, Uppsala University, started to study the populations of collared flycatchers on Gotland and put up nest boxes. According to Qvarnström and Wiley (Interview with Qvarnström and Wiley 6/3-2006) there are close to 3000 nest boxes today intended for flycatchers on Gotland. However, the collared flycatcher has taken over almost completely and out of about 900 flycatcher couples on Gotland, only as few as approximately three couples are pied flycatchers. The rest are collared flycatchers.

In 2001 Anna Qvarnström put up nest boxes on Öland, where the ratio of pied flycatchers is still higher than on Gotland. 2000 nest boxes have been put up and out of 300 couples of flycatchers that come to Öland to breed, around 50 couples are pied flycatchers. There are also around ten mixed couples and a few hybrid pairs each season (Interview with Qvarnström, Wiley and Svedin 4/4-2006). The birds are ringed, which means that rings with an identification code are put around one of their legs. That makes it possible for researchers to track individual birds as well as family relationships.

In the summer of 2006, during this degree project, Qvarnström won the highly prestigious European Young Investigator Award (EURYI) for her excellent research (Vetenskapsrådet 29/8-2007). The funding is comparable in size to the Nobel Prize.

3.3.2 Research findings

Qvarnström and her associates have discovered that the fitness of collared flycatchers is more sensitive to seasonal decline in environmental conditions, than the fitness of pied flycatchers. In other words, even though collared flycatchers are dominant in interference competition with pied flycatchers, collared flycatchers are not as successful breeders during harsh conditions as pied flycatchers (Qvarnström, A., Svedin, N., Wiley, C., Veen, T. and Gustafsson, L. 2005).

Other interesting findings indicate that the cost for flycatcher females of choosing dominant males before subordinate males can sometimes outweigh the benefits. It is generally thought that winners of male-male competitions are of superior quality and that it would be beneficial to females to mate with these males. But studies show that traits important in competitions between males might not always be the same as those that are important to females selecting a mate (Qvarnström, A., Forsgren, E. 1998).

As a final example, another discovery made by the people working with the flycatcher project is that hybridisation between collared flycatchers and pied flycatchers is affected by so called delayed maturation. Delayed maturation means that young birds do not attain their full adult colouration until one or several years after reaching sexual maturity. This signalling of

juvenile status is thought to protect young birds from aggression coming from older, more dominant adults. However, juvenile male collared flycatchers can appear similar to adult male pied flycatchers and therefore attract females of the wrong species (Wiley, C., Bengtson, J.M., Svedin, N. and Qvarnström, A., 2005).

4. Project setup

This chapter explains the project background, how maps and GPS equipment were used, how the fieldwork was carried out and finally how the collected data was processed.

4.1 Project background

The original idea for this degree project was to test wireless sensors for biology purposes. That was how I got in touch with Qvarnström and her associates and the plan was to put the sensors inside nest boxes to measure temperature differences. After that a web application would be created, visualising the results. After months of work, it was discovered that the sensors were unable to measure the needed temperatures. It was simply not possible to use them in the project. However, at the same time a discovery was made that the biologists had big problems with their field maps.

The biologists used hand drawn black and white field maps, consisting of lines and nest box ID numbers. Most of the maps lacked scales, cardinal directions and roads. The nest box positions were marked with their corresponding ID numbers, but their actual placements in the field were not always as they appeared on the map, which every new field worker soon found out. A field map over a nest box area can be found in Appendix 3. These problems illustrated the need for new field maps with accurate nest box positions. Since I had previously created maps for biology research during a GIS course, I knew it would not be difficult to create new maps. An idea emerged of creating an interactive map application just like in the original plan, but instead of temperatures visualise parts of the biologists collected bird data. With the same map material it was also possible to create new field maps, something that the biologists were very interested in, although that work is not included in this thesis.

Now the task was to collect GPS positions of the nest boxes, acquire digital maps of Öland and make an interactive web application showing the nest boxes on the maps. This would then be combined with collected data about the nest boxes' inhabitants, such as number of laid eggs, number of full-fledged chicks etc.

4.2 GIS

In this chapter, explanations are given about the maps and GPS equipment that were used in this project, together with the solution of a delicate problem regarding translation between Swedish and international geodetic reference systems.

4.2.1 Maps

To begin with, maps were downloaded from the Digital Map Library. The General map (Översiktskartan), an overview map in scale 1:250 000, was chosen to show where the nest box areas were situated on Öland (Digitala Kartbiblioteket 27/8-2007). The Property map (Fastighetskartan), Lantmäteriet's most detailed map in scale 1:20 000, was chosen for plotting the nest boxes on each nest box area. All maps were in the same Swedish geodetic reference system, RT90 (also called Rikets nät) and downloaded as shapefiles. The shapefile

format, developed by ESRI Sweden, consists of at least three files: .shp which stores the actual geometry points in a vector format, .shx which stores the index data pointing to the geometry structures in the .shp file and .dbf, which stores the attributes in database format (Hårdén, 2005).

4.2.2 GPS receivers and settings

With help from a number of biologists, I positioned nest boxes on Öland, using GPS receivers. Only a few of the biologists had actually used a GPS before and since no one had time to teach them how to use the equipment properly, I created a GPS crib (shown in Appendix 2) for educational purposes.

We used three different GPS receivers to collect positions of the nest boxes: eTrex, GPS 12 (Figure 10) and GPS 12 XL, all manufactured by Garmin International Inc. All the models are quite old, but according to Göran Hammer, associated professor at the Department of Social and Economic Geography, Uppsala University, the GPS 12 and GPS 12 XL are of very good quality; robust and reliable out in the field (Interview with Hammer 13/9-2006).

Figure 10. My GPS equipment, a Garmin GPS 12. (Image by the author)

The eTrex model seemed to use slightly different settings than the other two models, GPS 12 and GPS 12 XL. It was also smaller and used two batteries instead of four, which made me suspicious about its exactitude. Since the other two models used practically the same software, a decision was made later on to primarily stick to using them instead of eTrex, to minimise possible differences between collected coordinates.

The downloaded maps used the Swedish reference system RT90. In the GPS 12 and GPS 12 XL settings, the RT90 reference system and a format called Swedish grid were chosen, to get the GPS positions in the same format as the maps. However, after my first visit to Öland, I by accident stumbled over a web page on Lantmäteriet's website, advocating other customised settings than the already available RT90 and Swedish grid for the Garmin GPS 12 and GPS 12 XL models:

"By using a carefully selected projection instead of RT90 and Swedish Grid it's possible to enhance the connection in e.g. Garmin GPS 12 by choosing a so called User grid in Transverse Mercator." (GPS och annan mätningsteknik, 7/11-2006)

According to another web page (Bättre att paddla med GPS?, 7/11-2006) the Garmin models' algorithm for the Swedish reference system is flawed. Because the manufacturer is international, the GPS software is based on the international reference system WGS-84 and latitude and longitude format. WGS-84 stands for World Geodetic System 1984 and is a global system constructed by American authorities for GPS (Tredimensionella system, 7/11-2006). An algorithm has then been used to translate the WGS-84 positions into Swedish RT90 positions, although there is a translation fault causing a 5-15 metre offset in the south of Sweden. At most, this translation fault causes a 28 metre difference in the south of the Baltic sea and in the far north of Sweden. By adjusting the settings manually with a number of specific parameters, the GPS 12 and GPS 12 XL can acquire more precise positions for our Swedish reference system. On my second trip to Öland, these new customised settings were used in the GPS receivers.

4.3 Working in the field

During the two trips to Öland, five days in May 2006 and two weeks in June 2006, I collected GPS positions of the nest boxes. It was better to gather GPS positions in May, before leaves appeared on the trees, which would have affected the GPS receivers' connection with the satellites.

While being down on Öland, I also got to help the biologists in their work. Count newborn chicks, determine the chicks age, label blood samples, put up traps and catch adult birds for measuring were some of the things I learned to do. Other activites included building aviaries, large outdoor birdcages which allow the birds to fly and breed in captivity, water birds and clean nest boxes from old nests, dead bats and other exciting (sometimes frightening) content. This gave me an insight in the biologists' work, which proved useful later on while working with the collected bird data.

4.4 Data processing

To transfer the GPS data to the computer, a freeware version of a program called GPS Utility 4.20 was used. A number of different output formats were available, but the database format DBF was chosen because it was supported by Microsoft Excel. The reason for this choice was that the biologists all use Excel for their collected data. They later transfer the data to a

statistical analysis application called JMP by SAS Institute (Interview with Qvarnström, Wiley and Svedin 15/3-2006).

With the biologists' help, close to 1600 nest box coordinates had been collected. These coordinates were then put together and processed. False coordinates (created by accident) were deleted, extra fields showing GPS, settings and paths to source files were added, duplicate coordinates were replaced by means and all coordinates were rounded off to whole meters. Showing decimals was pointless since the accuracy was between 5 and 15 meters anyway. All nest boxes were also stored with their full ID, which meant both area code and ID number in the same column (*i. e.* "KOL54"). To split them up into separate columns, a macro script was created in Excel.

Moreover, the biologists provided their collected bird data from four field seasons, to be utilised in the application.

5. Application and visualisation of data

Having acquired GPS positions, basic maps and bird data, all that was left was to create the final web application. The following paragraphs explain my choices of application software and setup. It also describes prototypes and gives a basic explanation of how the application works, together with code examples and screenshots.

5.2 Choosing software

The first idea was to transform the digital maps, with nest box positions on them, into ordinary JPEG-files. Then regions of the JPEG-pictures would be made clickable with HTML, together with different scripts for web pages. The point with using a reference system would then of course be lost. Figure 11 shows a first mock-up page of how a map on a web page could look.
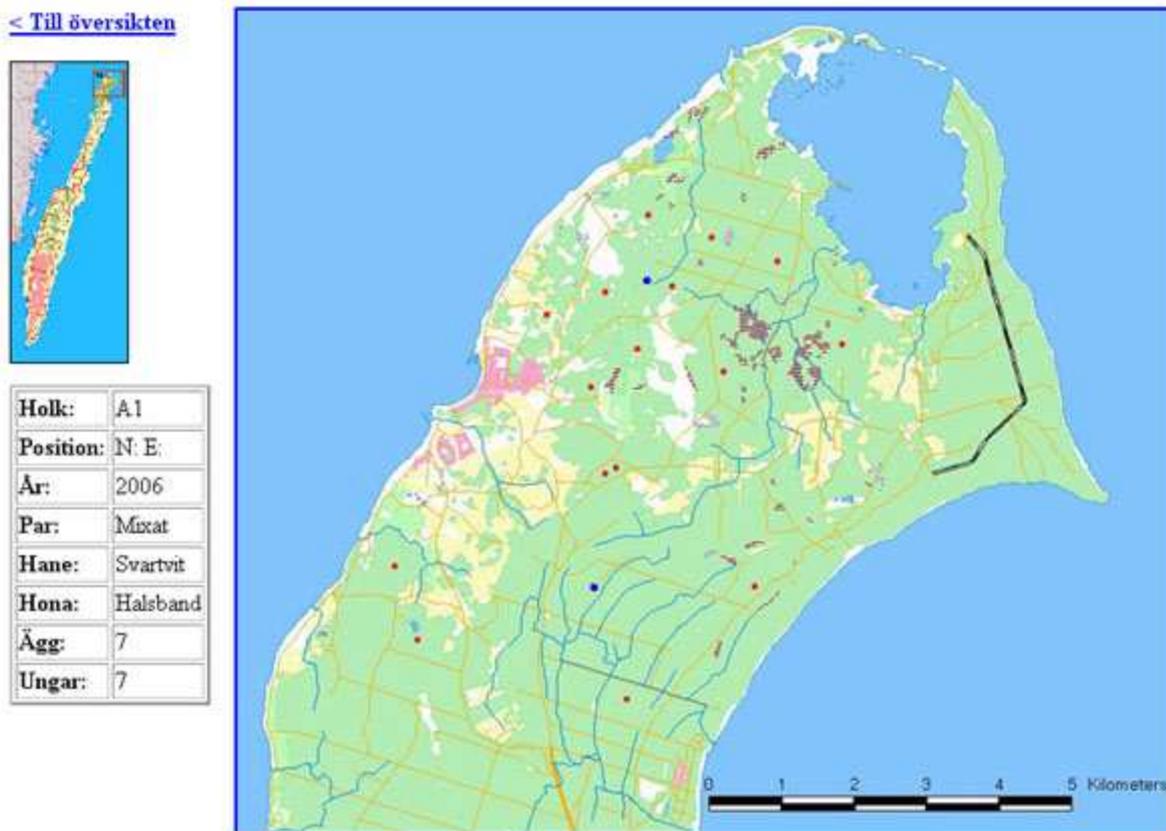
Figure 11. First mock-up of the application. This was made before I had even been to Öland. (Image by the author)

After the visit on Öland, a better software solution than the first idea was found: an open source development environment called UMN MapServer, by University of Minnesota, for building spatially-enabled internet applications (UMN MapServer, 7/11-2006). MapServer creates interactive maps out of geographic data such as shapefiles or database data. Basically

it is a CGI program on a web server and it renders map images out of the geographic data files provided and URL requests (Figure 12). CGI stands for Common Gateway Interface and is a standard protocol for interfacing external application software with a web server (Wikipedia, 7/11-2006). This was exactly what was needed to build the application. MapServer offered support for both reference systems and PHP, PHP Hypertext Processor, a server-side script language I was already familiar with. MapServer was also free to use, which was another essential requirement.
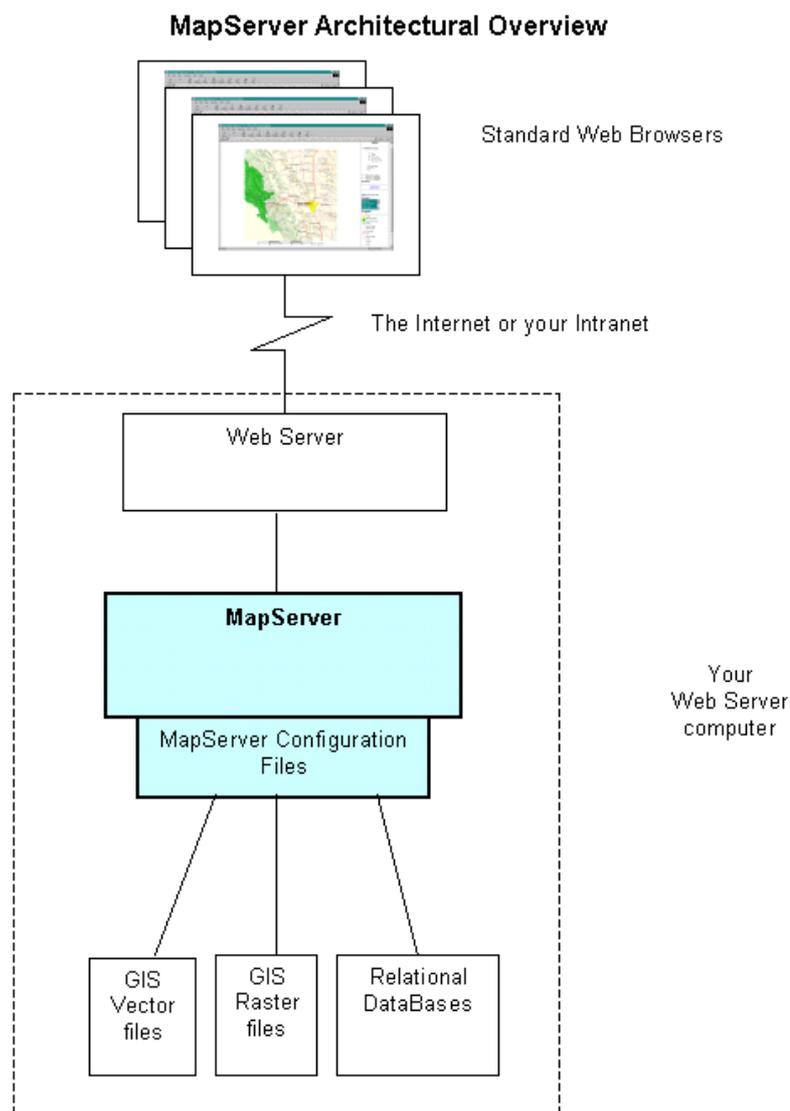
Figure 12. A typical MapServer Application. (Image by Fraser, 6/6-2007)

In a survey of different web based open source GIS solutions, UMN MapServer got a good grade (Böhm and Kunert, 2005). According to Böhm and Kunert, UMN MapServer is a very popular server with good documentation and it also has a large, active online community, which can be a most helpful resource. Mitchell (2005) states that MapServer makes it possible for users to create maps without needing particular tools installed or assistance from

specialised mapping analysts. The ability to simultaneously use a number of diverse data formats without conversion is one of the major strengths of MapServer (Mitchell 2005; Erle, Gibson and Walsh 2005).

To be able to use MapServer, a web server to install it on was needed. A database to ease spatial queries was also preferred and the MapServer homepage recommended a PostgreSQL database with a PostGIS extension. PostgreSQL is a powerful, open source object-relational database system originally created at Berkeley, University of California (PostgreSQL.org, 7/11-2006). PostGIS is a PostgreSQL extension (Figure 13) which offers database support of GIS objects and "spatially enables" the database (PostGIS, 7/11-2006).
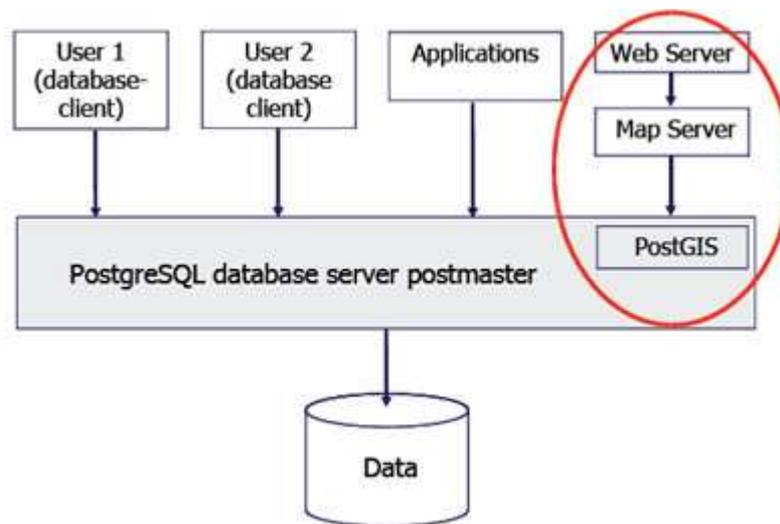
Figure 13. How PostgreSQL, PostGIS, MapServer and the web server are connected. (Image by Christl, 6/6 2007)

Most web hosting services turned out not to offer PostgreSQL to their customers. Finally a friend of mine, Thomas Tydal, offered a cheap account at his web hosting service and he installed PostgreSQL, PostGIS and MapServer for me.

5.3 Using MapServer

Apart from a tricky installation and configuration process, MapServer turned out to be quite easy to use. Its main component is the so called mapfile. The mapfile defines relationships between objects, points MapServer to where data are located and defines how objects are drawn on the resulting web page (UMN MapServer, 4/12-2006). In the mapfile, the geographical data are mapped in a hierarchical structure with layers and classes, together with a set of styling attributes such as colour, size, position, font and more. Below is an example of a simple mapfile with one layer.

```
MAP                                         # Start of MAP object
   SIZE 400 400                             # 400x400 px output image
   EXTENT -25 50 -65 24                     # Map extent coordinates

   SCALEBAR                                 # Start of SCALEBAR object
     STATUS EMBED                           # Embed scale in map image
     UNITS KILOMETERS                       # Units of map coordinates
     INTERVALS 3                            # Scalebar breakups
     TRANSPARENT TRUE                       # No background colour
     OUTLINECOLOR 0 0 0                     # RGB code for outline
   END                                      # End of SCALEBAR object

   LEGEND                                   # Start of LEGEND object
     STATUS ON                              # LEGEND visible
     TRANSPARENT TRUE                       # No background colour
   END                                      # End of LEGEND object

   LAYER                                    # Start of LAYER object
     TYPE LINE                              # Line shape type
     STATUS DEFAULT                         # LAYER always showing
     DATA "/data/oland1.shp"                # Source dataset

     CLASS                                  # Start of CLASS object
       NAME "Small roads"                   # Caption shown in legend

       STYLE                                # Start of STYLE object
         COLOR 0 0 0                        # RGB code for line colour
         WIDTH 2                            # Line width in pixels
       END                                  # End of STYLE object

     END                                    # End of CLASS object

   END                                      # End of LAYER object

END                                         # End of MAP object
```

To start learning MapServer, new users are encouraged to download a demo application with an interactive example map. It already has a couple of features built-in: pan, zoom in and out and turn on and off different layers. Users can simply change map source data (*i. e.* shapefiles) and bit by bit remodel the demo into their own application.

Using shapefiles in a MapServer application is pretty straight forward, as shown in the mapfile code example above. For more complicated spatial queries, it is better to keep the data in a database with PostGIS (Ramsey 11/7-2007). It is more difficult to set up, but PostGIS is faster and offers a number of built in functions, such as `area()`, `distance()` and `transform()`. For example it can calculate the area of a complex forest, single out all nest boxes that are situated less than 100 meters from a building and transform coordinates from one reference system to another.

A web interface called phpPgAdmin, provided by the web hosting service, was used to administrate the PostgreSQL database. The collected bird data was transformed from JMP's own format (also called JMP) via TXT format to SQL commands and then entered into the database.

Below is a subset of my mapfile layer code showing database data about pied flycatcher families in the area of Kohagelyckan collected in summer 2005. The pied flycatcher ('PF') families are singled out from the database table by ordinary SQL commands in the DATA string.

```
# Svartvita flugsnappare 2005

LAYER
  NAME Pied2005
  TYPE POINT
  CONNECTIONTYPE postgis
  CONNECTION "host=localhost user=fia password=*** dbname=fia
    port=5432"
  DATA "geom from (SELECT kohagelyckan.geom AS geom,
    FROM kohagelyckan, families_kohagelyckan2005
    WHERE kohagelyckan.box = families_kohagelyckan2005.box
    AND ((spm = 'PF' AND spf = 'PF') OR (spm = 'PF' AND spf = '')
    OR (spm = '' AND spf = 'PF')))
    as foo using srid=-1 using unique box"
  STATUS OFF
  SYMBOLSCALE 2000

  CLASS
    NAME 'Pied flycatchers'
    SYMBOL 'circle'
    COLOR 100 100 255
    OUTLINECOLOR 0 0 0
    SIZE 8
    MINSIZE 8
    MAXSIZE 20
  END

END
```

MapServer processes the instructions in the Mapfile and generates maps as image files presented on a web page. As with most data inputs and outputs for MapServer, the user gets to specify what kind of image the application will generate and a wide range of formats is supported. I chose JPEG output.

To add interactivity, the web page contains an HTML <FORM> with input controls, such as buttons, checkboxes and lists. But the most important input control is the map itself. The image is not presented as an ordinary <IMG> element, but an <INPUT> control. When the user clicks on it, the coordinates of the clicked pixel are submitted with the form. It causes the web page to reload and a new map image to be loaded, based on the information sent from the <INPUT> controls. That interaction chain is the basis for zooming and panning.

5.4 Designing a prototype

This chapter begins with a brief explanation about different kinds of prototyping. Then explanations are given about the design choices made and the chosen functionality.

5.4.1 Prototyping

A prototype is a concrete representation of a system design, although not fully developed (Benyon *et al*. 2005, pp. 253-260). Prototypes can be divided into two main kinds: low fidelity, lo-fi, and high fidelity, hi-fi. Lo-fi prototypes are usually made of paper, while hi-fi prototypes are produced in software. Lo-fi prototypes can be quickly produced and focus more on underlying design ideas, such as navigation and structure. Hi-fi prototypes, on the other hand, look and feel more like the final product. They take longer to produce, but are more useful for detailed evaluation and usability studies.

Prototypes can also offer different levels of functionality. A horizontal prototype shows the whole system, but only includes broad, general functions. Much of the detail is omitted. The opposite is a vertical prototype, which implements the full range of features for a small number of functions (*ibid.*). Of course, there are also combinations of both.

Furthermore, there are different methods of prototyping. Evolutionary prototyping and throwaway prototyping are two well-known methods (Vliet 2004, pp. 53-55). Evolutionary prototyping starts with raw requirements, which lead to a first version. When the user starts working with the prototype, new or changed requirements emerge. This leads to new versions and more feedback. After a number of such iterations the prototype has evolved into the final product. In throwaway prototyping, prototypes are created but used only as a specification for the final product. In that way the quality of the final design is often higher because of the learning experience through the prototypes.

5.4.2 Design and basic functionality

With a demo application ready to use, it was easiest to start with a hi-fi prototype, especially due to the lack of previous experience of this software.

From a total of about 17 nest box areas positioned with GPS, two were selected for implementation: Lilla Hult, one of the smallest areas with only 34 nest boxes and a map size of 0.6 square kilometres, and Kohagelyckan, one of the biggest areas with 152 nest boxes and a map size of 1.9 square kilometres. A vertical prototype offering more functionality for two areas was a logical choice, rather than implementing all areas with lesser functionality.

Figure 14 is a screenshot of an early version of the application. The original example application contained the same input controls and after a while they turned out to be inefficient in the application. For example, the listbox for choosing layers showed redundant information by combining all years with all species constellations. Even with a listbox height of ten lines, the user would need to scroll to access all layers.

Lilla Hult
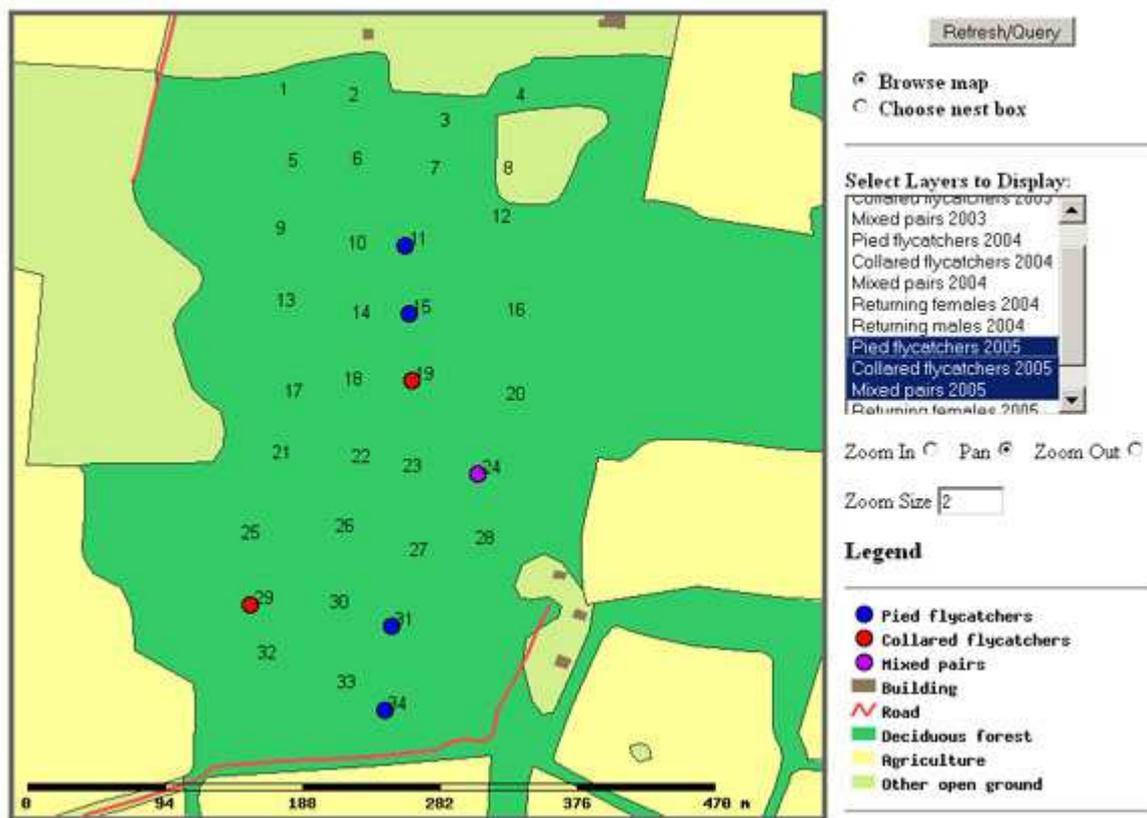
Figure 14. Screenshot of Lilla Hult nest box area, early version. Nest boxes are marked with box numbers. Blue dots indicate breeding pied flycatchers, red dots collared and purple dots mixed pairs. (Image by the author)

To find a better solution, a mock-up web page was made of paper, with loose elements to model a new design, a lo-fi prototype. It was quicker to work with than a real web page. Unfortunately, the elements were not to scale, so the result was too flawed to be used. However, while trying different combinations of the paper puzzle, it became obvious that some input controls could be redesigned to take up less space and those findings proved useful in the next versions of the application. Figure 15 presents the two ideas for layer control.

Figure 15. Listbox compared to checkboxes. The listbox together with refresh button in the previous version (left) takes up more space and sometimes requires the user to scroll, compared to the checkboxes in the newer version (right). (Image by the author)

Which input controls to use depended on what functionality the biologists wanted the application to have and the method of evolutionary prototyping was used to clarify that. From the start, the biologists were unsure of what visual functions the web page could offer. Without previous experience, they simply did not know what such a map application could do. I did not know it either until I started experimenting with the application and discovered new ways to combine and show bird data. To inspire the biologists a decision was made to create a hi-fi prototype with a set of basic functions and a few more complex functions. Basic functions were to choose between different nest box areas and to divide bird couples by species, as well as mixed pairs and hybrids, the latter being of extra interest to the biologists. Another basic function would be to choose a certain nest box and show its family data for a chosen season.

When working with the web page, it was soon discovered that it was impossible to fit all the controls and information on one screen. So I came up with the idea of having several pages showing the same area, but with different themes and a menu to navigate between them. This was also advocated by Olsson (2003, p. 44), who stated that it is often better to spread out large amounts of information over a series of maps than overloading a single map with too much information. Figure 16 shows a later version of my application with a more space efficient design. Tabs are used to navigate between related maps.
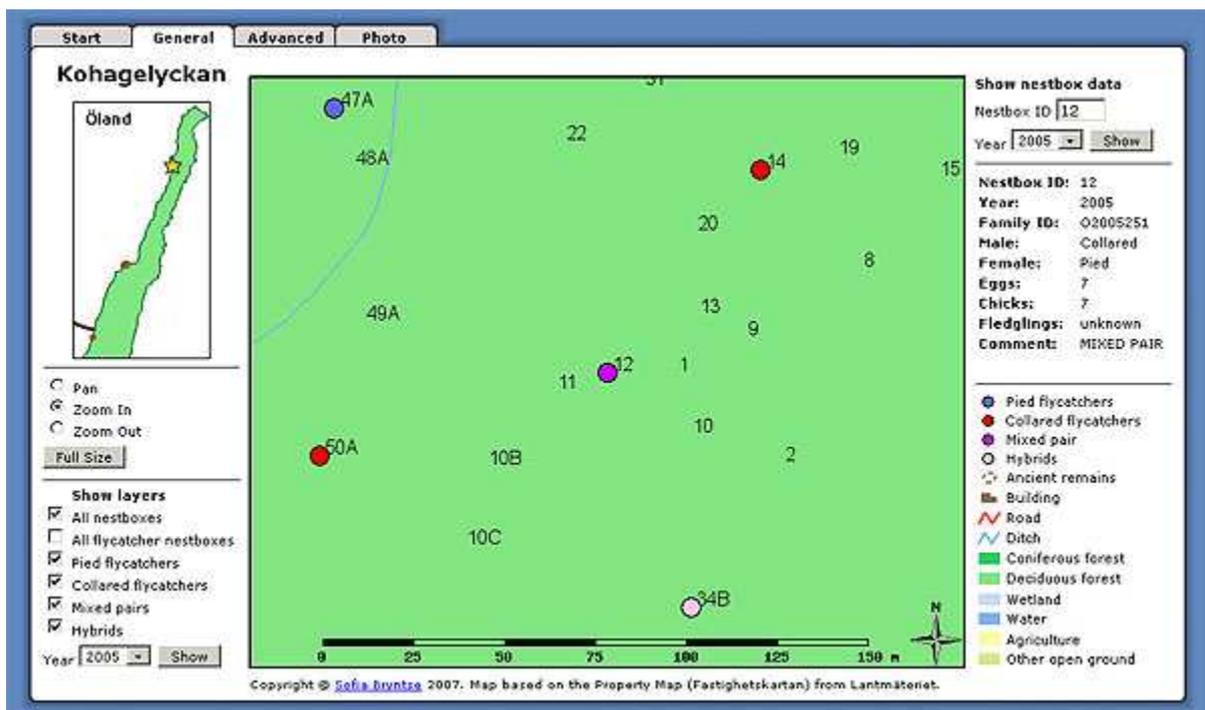
Figure 16. Screenshot of Kohagelyckan nest box area, with a more space efficient design. Notice the navigation tabs, checkboxes and reference map. (Image by the author)

The "Show nest box data" function shown in Figure 17 offers the user to write the ID of a nest box and choose to see the data collected about that nest box a particular year. Not all data are shown because of the limited space.

Figure 17. The Show nest box data function. Detailed information about nest box 12, year 2005, is presented. (Image by the author)

When showing the prototype to the biologists, it would be an advantage if it looked good on their screens. Benyon *et al.* (2005, p. 254) states that a problem with hi-fi prototypes is that they look so close to the real system that people believe it is the real system. For that reason, it is vital that the details of the prototype are accurate, otherwise the users might become confused. The web page was adjusted to the most common screen resolution. In January 2007 54% of the Internet users used a resolution of 1024 x 768 pixels (Browser statistics, 12/7-2007). I did not know for sure which browser the biologists used, but many of them used Mac computers so it was made sure that the web page looked the same in the most likely used browsers. In June 2007 Internet Explorer had about 60% of the users, Mozilla Firefox (my favourite) 35% and Safari (Mac browser) about 1% according to W3schools Browser statistics (12/7-2007).

5.4.3 More complex functionality

As an example of a slightly more complex set of functions, a visualisation of the different stages that the chicks go through over time was made. The bird data for each nest box included the lay date of the eggs, hatch date of the eggs and survival data for eggs and chicks. Homemade icons illustrating eggs, hatchlings, chicks and fledglings represented the separate layers in the mapfile. Drop-down boxes with weeks and years were then connected with the layers and depending on the date, each nest box would show its current "chick status". Figure 18 shows the icons.

Figure 18. Icons showing the different stages of flycatcher eggs and chicks. (Images by the author)

The colours of the eggs and chicks are chosen to imitate real flycatcher colours. The icons are also designed to be scalable to a certain extent in MapServer, because of the zoom in and out function. Figure 19 shows a screenshot of the Chicks evolution functionality.
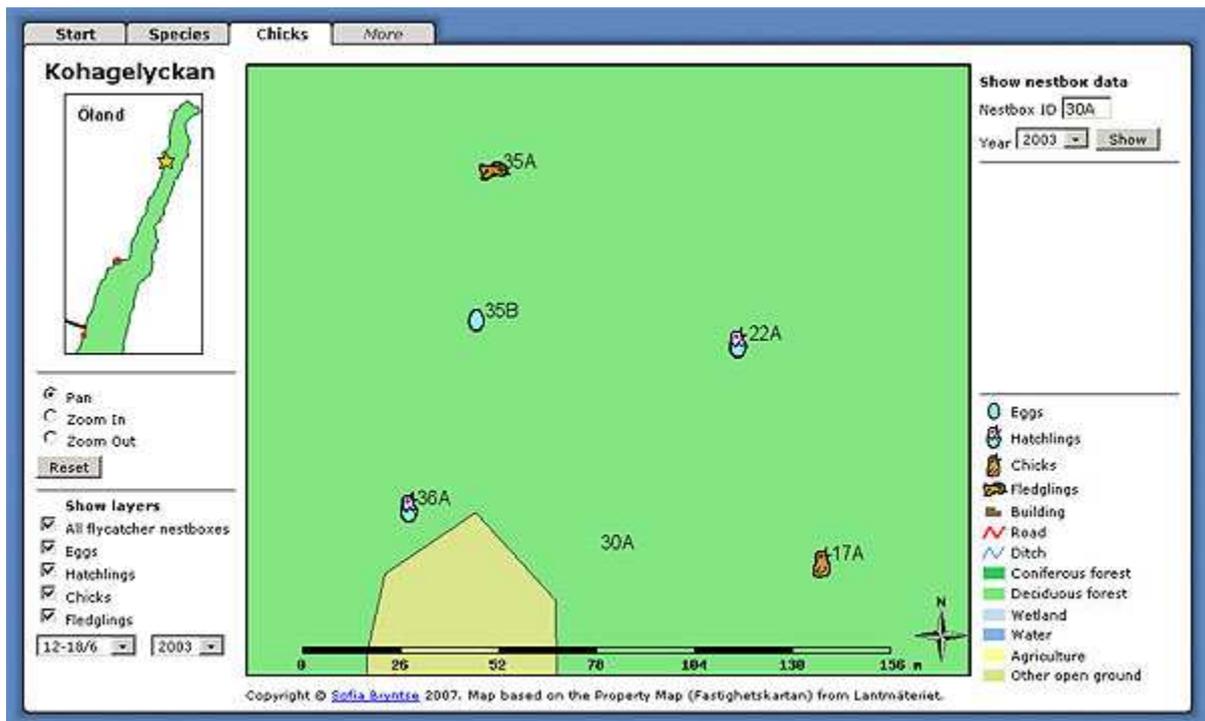
Figure 19. Chicks evolving. Screenshot of Kohagelyckan nest box area in 2003, 12 to 18 of June. The icons visualise the different stages of the chicks during that particular week. (Image by the author)

A second complex function was also tried; to be able to show which males and females that had either been born or bred at that particular area a previous year and returned for another season. It was desirable to show adults (two years or older) and juveniles (one year) in separate layers. Unfortunately it did not work the way it was supposed to. Showing birds that returned after only one year was no problem, but when attempting to show the birds returning after more than one year, the application crashed. It seemed like the structure of the database caused the problem. The database was divided in separate tables for each area and season, *i. e.* "Families Kohagelyckan 2002", "Families Kohagelyckan 2003" etc. The chicks also had their own separate tables each year. To see which birds had returned in the year of 2005, PostgreSQL needed to search through six different tables and that was obviously too much, at least with the long and complex SQL commands I had written.

5.4.4 Accommodating the biologists needs

When meeting the biologists, they were very pleased with the existing functions that had been implemented (Interview with Qvarnström, Svedin, Thörngren and Vallin 20/8 2007). However, they seemed unsure of which new functions to add. A few minor changes were proposed, such as showing some statistics so they would not have to count the depicted nest boxes. A few other ideas were too excessive for my prototype: an interface for adding new areas and bird data, and an overview of how the collared flycatcher population is expanding on Öland. The latter would mean adding all four years of collected bird data to the database.

As for the bigger picture, the biologists came to think of two purposes with my application. One was to use it in university courses, to educate biology students. The other was to illustrate scientific articles and presentations with appropriate screenshots. Both would need permissions from Lantmäteriet first.

A decision was made to help the biologists by adding more areas and make the prototype more horizontal. It was the closest way to accommodate their need for adding more data, within the limited scope of the project. One new big nest box area was added: Halltorp, with 175 nest boxes and a map size of 2.6 square kilometres. A statistical function, shown in Figure 20, was also added.

Figure 20. The species statistics functionality. This example shows Halltorp nest box area in 2005. (Image by the author)

Acquiring the statistics for each year was simple. The problem was instead where to show it. As seen in Figure 16, there was not much free space. Showing just the numbers on the legend or next to the layers was a first idea, but the space for it was too narrow. Then it was discovered that the "Show nest box data" space was used only when a particular nest box was examined. The rest of the time it was blank, as shown in Figure 19. The solution was simple: when the user did not ask for a particular nest box, the statistics could be shown in the free space instead.

5.4.5 The final prototype

The final prototype included double the amount of added nest boxes. Moreover, many of the usability problems that were identified through the heuristic evaluation, described below in chapter 5.6.3, were solved. Figure 21 shows a screenshot of the final prototype. Among other things, the nest box areas got linked together more closely via the reference map, so users did no longer have to go back to the start page to navigate between areas. The flycatcher box numbers were also standing out with the layer "All nest boxes" on, due to a 1 pixel horizontal offset in their position, which caused a "bold" effect.
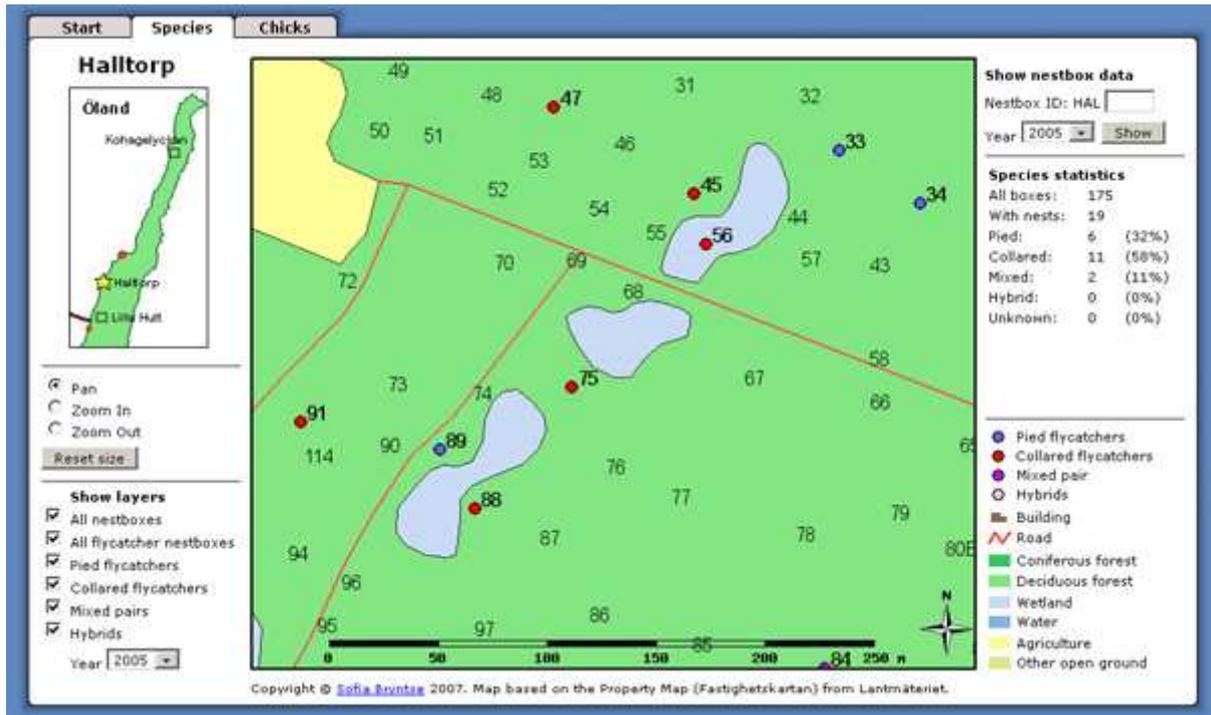
Figure 21. Screenshot of the final prototype. Note how nest box ID:s with breeding flycatchers look bold. (Image by the author)

One problem mentioned in the usability testing was that users were forced to go back to the start page, via the tabs, to navigate between areas. By showing all area names on the reference map and turn them into hyperlinks, users were no longer forced to use the start page. Figure 22 shows the new reference map features.

Figure 22. The new reference map with navigation functionality. (Image by the author)

The current nest box area is marked on the reference map with a yellow star, while the other areas are shown as rectangles. The area links on the reference map are also function specific,

which means that on a Chicks page, the links go to the other areas' Chicks page, thus making it possible to traverse the web site both vertically and horizontally.

Moreover, one more complex functionality was included in the final version. Out of curiosity I had added a function for showing orthophotos of nest box areas. Orthophotos are aerial photos which projections have been corrected to compensate for the scale distortions inherent to photographs (Hall *et al.* 2003, p. 158). There were two main reasons for implementing an orthophoto function. First, the biologists would most likely not have thought of this possibility themselves. Second, I was reluctant to ask them before I knew if it was technically possible and thereby create false expectations. Figure 23 shows the orthophoto functionality.
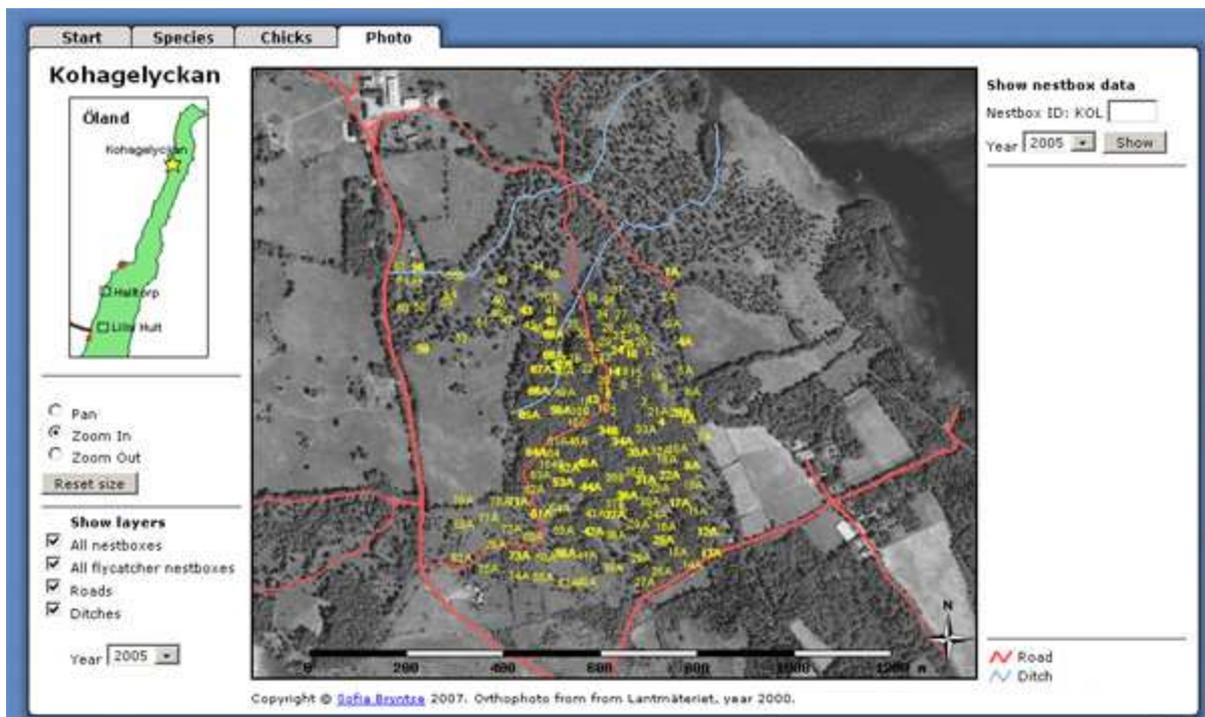
Figure 23. Orthophoto of Kohagelyckan nest box area. Roads and ditches are marked with red and blue lines. (Image by the author)

Orthophotos of nest box areas offered a new level of detail to the biologists, since landmarks such as individual trees and small glades became visible. When working in the field, the veteran biologists use memorised landmarks more than field maps for navigating in the nest box areas. Therefore orthophotos should be more appealing to them than the less detailed maps based on the Property map.

5.5 Implementation

Apart from specifying layers in the mapfile, all coding was done in HTML, CSS, PHP/MapScript and JavaScript. The following paragraphs will explain the implementation in a little more detail.

5.5.1 HTML and CSS

The design and input controls were all done in regular HTML. Form data was submitted with the GET method, which is preferable when the processing of the form does not leave a lasting observable effect (Hypertext Markup Language, 23/8-2007). The GET method sends data as part of the URL. This is also a huge advantage when testing an application, even though too many parameters can seem confusing for the user since they are visible in the web browser's address field.

Cascading Style Sheets, CSS, was also used. With CSS it is possible to create global custom style classes with instructions for how to draw a certain element. Font size, margins and colours can be specified in one single file that is included in all HTML files.

5.5.2 PHP/MapScript, JavaScript and SQL

MapServer offers support for PHP/MapScript, a specially developed object-oriented version of PHP. Regular PHP is executed on the web server by an interpreter, which generates and sends an ordinary HTML page to the client. However, PHP/MapScript implements all objects in the mapfile, `<MAP>`, `<LAYER>` etc, as PHP classes with corresponding attributes and methods.

The `<FORM>` inputs were combined with both object-oriented methods, like setting visibility status for layers, and more regular PHP programming. That made the application more flexible, since there was often more than one way to solve a problem. For example, when MapServer refused to auto-generate a legend over visible layers for unknown reasons, I could do some workarounds. With hand drawn icons and simple `IF` statements, legend icons were made visible depending on their corresponding layers' visibility status. It may have been a bit more work for me, but on the other hand it was more efficient to include already made pictures than letting MapServer redraw them every time the web page refreshed.

Short bits of JavaScript were also used on a few places. It proved useful when it was needed to submit forms following a different event than clicking a submit button.

To manage the PostgreSQL database, SQL was used to create and fill tables, as well as retrieving data for the map layers.

5.6 User testing

Several user tests were arranged, to get requirements feedback for the application, both for functions and usability.

5.6.1 First test

First, my colleague Maria Forsberg, an expert in human-computer interaction, tried the same version as in Figure 16, in July 2007. It was a small informal test. On purpose she was not informed of the exact interface functionality, but encouraged to explore the application on her

own. It proved to be a successful strategy, because her very first attempt to turn on layers did not succeed. She clicked the checkboxes for each layer, but forgot to press the "Show" button at the bottom. This revealed an obvious design flaw and would have gone unnoticed if it would have been explained to her how to use the input controls. After the testing the unnecessary "Show" button was removed and a piece of JavaScript code was added on each checkbox instead. After that, clicking a checkbox triggered the form to submit and the page to reload. There was no need for an extra button.

5.6.2 Testing on biologists

The second user testing was with the biologists a couple of weeks later. They were four biologists and we only had one computer to try the application on. When asked if any one of them would like to take a seat and explore the application, the biologists hesitated slightly. Trying a completely new computer application in front of a group of people obviously added a certain pressure to the situation and this made it impossible to use the same strategy as when testing the application on my colleague. Therefore I chose to help the biologist that started using the computer, by briefly explain the functionality to her. On the other hand, the main purpose of this testing and following brief interview was to find out new functions that could be added or perhaps changes in the existing functions, not so much to evaluate the user interface from a usability point of view. However, the result became a little bit of both.

The biologists gave a very positive response to the application version in Figure 17. "Appealing", "good overview" and "user friendly" were some of the comments (Interview with Qvarnström, Svedin, Thörngren and Vallin 20/8-2007). Never before had they been able to see such a visual presentation of the flycatcher distribution for each year. They were especially interested in how new data was added. The same question came by email from a fifth biologist. Expanding the application to include more areas and years of collected data was obviously something they were very interested in.

One immediate question was if it was possible to show the percentage of each species for a certain area and year. In that way they would not have to count the coloured dots. Another question was how to enter the nest box ID under "Show nest box data". Should it be with or without the three-letter area code? Both these remarks were easy to accommodate. A third idea was a desire to show the species distribution for all areas on Öland at once. The collared flycatchers are getting more and more common each year, at the same time driving out the pied flycatchers. It would therefore be illustrative to visualise how the collared flycatchers are taking over Öland (*ibid.*).

Later, a newer version was tested on the biologists and again they were asked what more improvements and functionality that could be useful to include. The biologists liked the orthophoto function and wanted to keep it (Email from Thörngren, 28/8-2007). Overall, the biologists were very pleased with the application and said it offered enough functionality already. A few possible ideas for the future came up, such as adding bird songs from the different species and using the application for analyses of temperature data. (Emails from Thörngren and Vallin, 28/8-2007)

5.6.3 Heuristic evaluation

Heuristic evaluation is an evaluation done by experts systematically checking an application against a list of heuristics, principles for measuring good design (Benyon *et al*. 2005, p.272). As it is advised to let several experts evaluate the application individually (*ibid.*), Forsberg and I both did separate heuristic evaluations of the version in Figure 16, following Jakob Nielsen's ten usability heuristics (Nielsen 23/8-2007*)*. The result is presented below, first showing the name of the heuristic with a brief explanation following. Under each heuristic is a list of the weaknesses and strengths that we found. An empty box (☐) means a problem that has not been solved, a box checked with a tick (☑) means that the problem has been addressed in the final prototype and a box checked with a cross (☒) means a positive remark.

1. Visibility of system status
The system should inform the users what is going on.
- ☑ Choosing nest box area through the radio buttons on the start page does not result in any visible changes. (Forsberg)
- ☐ No feedback as to what changes when you choose "zoom" or "pan". (Forsberg)
- ☑ If the layer "All boxes" is visible, no visible change appear when the "Flycatcher nest boxes" is turned on, because they overlap precisely. (Author)
- ☑ The first week in May is default for all Chicks pages. However, no eggs or chicks usually exist that early so nothing shows when the user turns on the different layers. (Author)

2. Match between system and the real world
The system should use conventions and vocabulary from the real world.
- ☒ Consistent use of language that is familiar to the intended users. (Forsberg)
- ☒ Icons of eggs and chicks are displayed in real-world colours, which means light blue for eggs, pink for newborn hatchlings and brown for chicks. (Author)
- ☐ The weeks on the Chicks page do not correspond to calendar weeks. (Author)

3. User control and freedom
The system should help users recover from mistakes.
- ☒ Good emergency exit with the "reset size" option for the maps. (Forsberg, author)
- ☐ Zooming out after showing nest box data for a particular nest box (which automatically zooms in on the chosen box), will make the nest box data disappear from the screen. (Author)

4. Consistency and standards
The system should be consistent to avoid confusion.
- ☑ Hitting Enter key in "show nest box data" in tab species seem to make random map change instead of being an alternative to hitting the show button. (Forsberg, author)
- ☑ The two year dropdown lists in the species and chicks tab seems to only be connected one way. If you search for a nest box a specific year, the map year also changes, but if you change the map year, the nest box year doesn't change. (Forsberg)
- ☑ Lilla Hult chicks page has a different scale than Lilla Hult species. (Author)
- ☑ The legend on the Chicks page is completely static, compared to the legend on the other page which changes according to which layers are visible and not. (Author)

☑ There are no nest box layers on by default, on the Chicks page, compared to the other page. (Author)

☒ The chosen colours of the maps are similar to conventional maps with red roads, yellow fields etc. (Author)

5. Error prevention

The system should as far as possible eliminate error-prone conditions.

☑ The two different ways of choosing between nest box areas, by radio buttons and hyperlinks, are confusing. (Forsberg)

☒ It is not possible to show nest box data from one year and map from another year at the same time. (Author)

☒ Users can not change any data in the database through the application. (Author)

☒ Maximum and minimum zoom levels prevent zooming in or out too much. (Author)

6. Recognition rather than recall

Objects, actions and options should be visible and thereby minimise the user's memory load.

☒ All options are visible at all times which make the burden on short term memory low. (Forsberg)

☒ Name of area, scale, legend and north arrow help the user. (Author)

7. Flexibility and efficiency of use

The system should support accelerators for expert users.

☐ Users can only turn one layer on or off at a time, between a new page reload. (Author)

☐ The drop down box for choosing week on the Chicks pages is not efficient to use. (Author)

☐ Users have to write the box ID in a text field when showing a nest box, instead of clicking on a box on the map. (Author)

☑ To navigate between areas, users must go back to the start page. (Author)

8. Aesthetic and minimalist design

The system should not diminish visibility of relevant units with irrelevant or rarely used information.

☑ Clear design, but the use of a "fake" tab to indicate more is to come is unnecessary since it only leads to confusion when you try to click on it. (Forsberg)

☑ The reference map is probably only needed the very first time. (Author)

9. Help users recognise, diagnose, and recover from errors

The system should give constructive error messages in plain language.

☑ No error messages when searching for nest boxes to indicate the difference between an empty nest box and one that doesn't exist. (Forsberg)

10. Help and documentation

When necessary, the system should support the user with extra help and documentation.

☒ No documentation needed. (Forsberg)

☐ There is no help, except for some text on the Start page and an email link. (Author)

Out of the 20 identified problems above, 13 were addressed in the final prototype. The remaining seven problems were either too complicated or too time-consuming to solve in relation to their importance.

6. Conclusion and discussion

This thesis describes the development of a GIS application for biological research. GPS positions for 1600 nest boxes were collected in forests on Öland and digital maps were downloaded from the Digital Map Library provided by Lantmäteriet. A development environment for creating map applications, UMN MapServer, was installed on a web server together with a PostgreSQL database with a spatial extension PostGIS and finally a prototype of an interactive map application was developed, combining maps and GPS positions with collected bird data from biologists. This chapter describes the results and problems that occurred.

6.1 Dealing with biology and geoinformatics

This has been a very transdisciplinary project, involving four different university departments within the subjects of biology, geoinformatics and information science (five if the original project with the sensors is counted). Hence the large diversity of references.

For me, spending time on Öland with biologists and participate in their work was the most fun part in this whole project. It was a huge contrast to working indoors in front of a computer. I learned a lot working with biologists, GPS equipment and maps. It was both exciting and required of me to master a few tricks. Some of my new skills include:

- How to get coordinates with the best accuracy when using a GPS receiver in a forest, where leaves hinder the satellite transmission.
- How to open a nest box while avoiding to get jumped by bird fleas. (Hold out a stick which the fleas jump on to and then you can open the box.)
- How to catch a bird in a nest box and hold it without harming it.
- How to adjust a GPS receiver to customised projection settings and keep the coordinates in the same format when transferring them to a computer.
- How to find out the corner coordinates of a map consisting of shapefiles.

My first visit to Öland was in the spring of 2006, at the same time as Sweden in horror watched how the bird flu spread over Europe. It was not easy to convince my mother that it was safe to go away and work with birds that had recently arrived from more southern latitudes. All the media coverage made it sound like doomsday. Nothing happened of course and today most people no longer think of the bird flu as a serious threat. Ticks on the other hand are thriving in the forests of Öland and for safety reasons I had to take three vaccination shots against tick-borne encephalitis, more known as TBE, before my trips.

6.2 Preparing the application

Preparing the application was more difficult than expected. It was troublesome to get MapServer, with all its related components and settings, to work the required way. Thankfully the web hosting service did an excellent job installing and configuring the software to make everything function the way it was supposed to. This extensive amount of work was actually carried out not only once, but twice because of a fatal hard disk failure on the server.

Both the GPS data and the bird data also needed a lot of work before they could be used. Many hours were wasted on trouble-shooting why the nest boxes would not show on the map, when I finally remembered that Swedens coordinate system RT90 uses opposite axes compared to mathematic systems and GIS. In RT90 the north-south axis is called the X-axis and the east-west axis is called the Y-axis, while in mathematics and most GIS software it is the other way around (Hauska and Harrie 2003, p. 77). The bird data also caused problems. The data in itself was very inconsistent and had to be inspected and corrected manually. For example, a nest box called A20 was the same as 20A, the letter O and the digit 0 were sometimes mixed up and both English and Swedish abbreviations, meaning the same thing, were used. The collected data was also fragmentary, meaning there were a lot of missing data that had to be compensated for when retrieving data from the database. The biggest problem however was the inefficient structure of the database, which obstructed more complex SQL queries. Unfortunately, restructuring the database tables was not possible within the scope of this project.

These necessary preparations, installing software and processing input data, took a lot longer than implementing the actual application.

6.3 Creating the application

Once all preparations were completed, creating the application prototype was not that difficult. Drawing images, programming for interactivity and exploring the PHP/MapScript Application Program Interface (API) was a lot of fun. Even so, I have only just scratched the surface of MapServer and the features it has to offer. It is possible to do so much more with it.

Creating a computer application for biologists was both fun and challenging. My experience is that many biologists are not so familiar with computers and the possibilities of software. This could be one of the reasons why the biologists I worked with were unsure of what purpose they could use the application for and what functions they would find useful. On the other hand, for that reason I have a theory that biologists may also be easier to please, since they don't have very high expectations from the beginning. Because of my previous work with the biologists, I consider myself familiar with their domain, to some extent at least. Therefore it was also easier for me to create a first version of the application, than it would have been for another software developer without interest and knowledge in the domain.

The method of evolutionary prototyping was used in this project, although it did not work out exactly as planned. Too much time was spent on the first version of the application, before testing it on the biologists. Benyon (2005, p. 260) identifies this problem: *"Realistic prototypes increase the validity of user test data, but may postpone testing"*. This was exactly what happened. In the end there was not much time left for more iterations and tests with the biologists. Another iteration was completed using the heuristic evaluations, which enhanced the user interface further.

6.4 Results

This thesis describes the development of a system prototype that visualises geographical and biological data for a research project about flycatchers. I used evolutionary prototyping as development method and only software I already had access to or could download for free. The efforts of creating this application are documented in this thesis. Despite the limited number of iterations, the final prototype featured three nest box areas, 360 nest boxes and 190 breeding flycatcher couples. The biologists have proposed to use the application for education of students as well as illustrating their research, in scientific articles for example.

The biologists could see the value of this application, though they were even more interested in the 18 new field maps I created for them. That was not really part of this project, but still very much related. Example of a new field map can be seen in Appendix 4. Compared to the old map, in Appendix 3, the nest box positions are more accurate on the new map, but there are fewer landmarks. (Note that north is downwards in the old map.) During the field season of 2007, the field assistants were already drawing extra landmarks on the new maps.

So how accurate is this application? Eklundh (2003, p. 28) claims that results from GIS based analyses can never be used uncritically. An inherent problem with GIS is that it can be used for very professional presentations of any data, regardless of quality. In the best of circumstances, the GPS positions should have an accuracy of 5-15 meters, depending on the reception when they were taken and the person using the GPS. However, with the first settings that were used, between 5-15 meters was added by default because of the GPS receivers' flawed algorithm for the Swedish reference system. Unfortunately the majority of nest boxes were positioned with these settings. Theoretically that means that some nest boxes may be drawn up to 30 meters from their actual positions.

The bird data shown in the application may also not be all accurate. Typing errors were discovered in the original data files (*e. g.* one flycatcher couple with "52" chicks!). It is also not easy to validate if the SQL commands used to retrieve data are 100% correct and compensating for all inconsistencies and missing values in the database.

An interesting fact appeared in the application, namely that the collared flycatchers on Öland are increasing in number each year. This is already known to the biologists of course, but to see how both numbers and red dots on the maps increase for each year adds a certain drama to it.

6.5 Legal issues

For copyright reasons, access to the page was granted to a limited number of users. This was done to keep the cost of publishing Lantmäteriet's material down. Around six biologists are known to use this application, only for themselves to start with. Because of the low number of users, I did not need a permission and did not have to pay any publishing fee to Lantmäteriet (Email from Lantmäteriet, 15/8-2007). The Digital Map Library exists for students and university employees, so research activities get a discount. If the biologists later publishes the page to students or use screenshots for presentations of their research, they will need a permission from Lantmäteriet and perhaps pay a fee.

Not only the maps are precious information from a legal point of view. Moreover, the biologists own bird data is very valuable and must be protected through restricted access, even if only a small fraction of the data is presented in the application.

6.6 Advices to other developers

My number one advice to other developers who would like to create their own MapServer application is: make sure you have good access to the web server, either directly or with the help of the server owner. This was vital for my project. Installing my own web server was never an option for me, so I had to find a web hosting service that could install the required software and configure it quickly when needed. A regular web hosting service could never have done this for me. Most of the time would surely have been spent on waiting on the phone for their customer support to understand and solve my problem.

Another good thing to know is that the Digital Map Library offers free access to maps of Sweden to students. The material is free to download and work with as long as it is not published to others.

6.7 Further work

With the basic functionality already implemented in this application, it is fairly easy to just add new nest box areas. There are 14 more nest box areas positioned with GPS and ready to be added right away. Moreover, there are probably another 10 areas to position, as well as new nest boxes that have been put up in some of the old areas. Bird songs and results from temperature analyses can also be added in future versions the application.

However, what is really needed is a new database structure for the bird data. It also needs to be cleaned from inconsistencies. That would simplify both adding new areas and adding more complex functionality to the application.

In a broader perspective, there are many more possibilities with this application than just visualising flycatchers on Öland. (Flycatchers on Gotland for example!) Seriously, with MapServer installed and a web application already made, all that is needed is any kind of geographic positions within Sweden and some kind of related data, to create an application with a new purpose.

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Interviews

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of Ecology and evolution, Uppsala University, 10/2 2006, 12.00.

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of Ecology and evolution, Uppsala University, 6/3 2006, 12.00.

Anna Qvarnström, assistant professor, Christopher Wiley, PhD student, and Nina Svedin, PhD
student, at the Department of Ecology and evolution, Uppsala University, 15/3 2006, 10.00.
(Available on tape.)

Anna Qvarnström, assistant professor, Christopher Wiley, PhD-student, and Nina Svedin,
PhD-student, at the Department of Ecology and evolution, Uppsala University, 4/4 2006,
14.00.

Anna Qvarnström, assistant professor, Nina Svedin, former PhD student, Hanna Thörngren,
PhD student and Niclas Vallin, PhD student, at the Department of Ecology and evolution,
Uppsala University, 20/8 2007, 10.30.

Göran Hammer, associated professor, Department of Social and Economic Geography,
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Hanna Thörngren, email, 28/8-2007.

Lantmäteriet, email, 15/8-2007.

Niclas Vallin, email, 28/8-2007.

Term	English definition	Svensk översättning
aviary	Bird cage big enough for flying.	Aviarium, stor flygbur för fåglar.
basemap	Map portraying background.	Bakgrundskarta.
collared flycatcher	*Ficedula albicollis,* a small bird species. In Sweden only be found on Öland and Gotland.	Halsbands-flugsnappare, *Ficedula albicollis*, en småfågel som i Sverige bara finns på Öland och Gotland.
Digital Map Library	A service open to students and researchers, for downloading maps of Sweden, provided by Lantmäteriet.	Digitala kartbiblioteket, Lantmäteriets karttjänst för nedladdning av Sverigekartor. Till för studenter och forskare.
ESRI	Environmental Systems Research Institute, a company that develops GIS software.	Environmental Systems Research Institute, ett företag som utvecklar GIS-program.
evolutionary prototyping	Method for developing prototypes through cycles of user feedback.	Metod för att utveckla protyper, genom cykler av användartester med feedback.
Darwinian fitness	The contribution an individual makes to the gene pool of the next generation, relative to the contributions of other individuals.	Arvet från en individ till nästa generations genpool, jämfört med arv från andra individer.
fitness	See Darwinian fitness or relative fitness.	Se Darwinian fitness eller relative fitness.
flycatcher	Type of bird, represented by several species.	Flugsnappare, en fågeltyp bestående av flera arter.
General map	An overview map of Sweden, in scale 1:250 000.	Översiktskartan, en karta över Sverige i skala 1:250 000.
genome	An organisms full set of genes.	Genuppsättningen hos en organism.
genotype	Part of an individual's set of genes.	Del av genomet hos en individ.
geoinformatics	Science which combines information science with regular geosciences.	Vetenskap som kombinerar informationsvetenskap med klassiska geovetenskaper.
GIS	Geographical Information System, a computerised system for manipulation, analysis etc of geographical data.	Geografiska informationssystem, ett datoriserat system för bearbetning, analys mm av geografiska data.

|		
GPS	Global Positioning System, a satellite navigation system.	Global Positioning System, ett navigationssystem via satelliter.
habitat	The area where a particular species or population lives.	Området där en viss art eller population lever.
heuristic	Rule of thumb.	Tumregel.
hi-fi prototype	High-fidelity prototype.	Naturtrogen prototyp.
horizontal prototype	Prototype showing the whole system, but only including the broad, general functions.	Bred prototyp av hela systemet, som bara inkluderar stora, generella funktioner.
human-computer interaction	The study of interaction between humans and computers.	Människa-dator-interaktion, område som studerar interaktionen mellan människor och datorer.
input control	Object that the user handles to communicate with a system, *e. g.* a button.	Objekt som användaren hanterar för att kommunicera med ett system, t ex en knapp.
legend	Explanation chart for symbols and colour codes in a map.	Symbolförklaring till en karta.
lo-fi prototype	Low-fidelity prototype, often made in paper.	Enkel prototyp som ej liknar slutprodukten. Ofta gjord av papper.
mapfile	The main file, in a MapServer application, that defines objects and layers and paths.	Huvudfilen i en MapServer-applikation. Definierar objekt, lager och sökvägar.
map projection	Method of how to portray the round surface of the Earth on a flat map.	Metod för hur man återger Jordens sfäriska yta på en plan karta.
MapServer	Development environment for building spatially-enabled internet applications.	Utvecklingsmiljö för att bygga spatiala internet-applikationer.
PHP/MapScript	Specially developed object-oriented version of PHP.	Specialutvecklad, objektorienterad version av PHP.
pied flycatcher	*Ficedula hypoleuca*, a small species of bird. Common in Sweden.	Svartvit flugsnappare, *Ficedula hypoleuca,* en småfågel vanlig i Sverige.
PostGIS	Extension to PostgreSQL for handling spatial data.	Tillägg till PostgreSQL för att hantera spatial data.
PostgreSQL	A database management system.	Ett databassystem.
Property map	Detailed map of Sweden in scale 1:20 000.	Fastighetskartan, detaljerad karta över Sverige i skala 1:20 000.
raster format	Conceptual storage format of geographical data, using a grid.	Konceptuellt lagringsformat för geografiska data via ett rutnät.

relative fitness	The contribution of a genotype to the next generation compared to the contribution of competing genotypes.	Bidrag av en genotyp till nästa generation, jämfört med konkurrerande genotyper.
RT90	National reference system for Swedish maps.	Även känt som Rikets nät, nationellt referenssystem för Sverige.
shapefile	Format for digital maps, developed by ESRI. A set of files (.shp, .shx and .dbf).	Digitalt kartformat, bestående av flera filer (.shp, .shx och .dbf) utvecklat av ESRI.
spatial	Spatial.	Rumslig.
transdisciplinary	Scientific approach to problems that transcend several subjects.	Transdisciplinär, nivå av tvärvetenskap.
vector format	Conceptual storage format of geographical data, built up by points, lines and polygons.	Konceptuellt lagringsformat för geografiska data, uppbyggt av punkter, linjer och ytor.
vertical prototype	Protoype that implements the full range of features for a small number of functions.	Smal prototyp som implementerar full funktionalitet för ett litet antal funktioner.
zygote	Fertilized cell.	Zygot, befruktad cell.

Lathund till GPS 12 och GPS 12 XL

* Slå på GPS:en (🔦) och håll den i vågrätt läge.

* Vänta tills GPS:en fått bra kontakt med satelliterna. (Tar oftast flera minuter när den varit avstängd en längre tid.) När det står **"3D"** uppe i vänstra hörnet betyder det att GPS:en är redo för mätning (fyra satelliter).
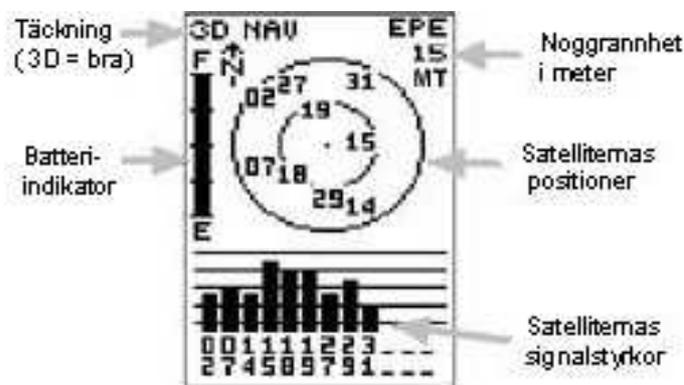
Satellitsidan

Spara en position

1. Kontrollera att det står "3D" högst upp till vänster på satellitsidan. Stå still på ett och samma ställe i ca 20 sekunder. Ju längre GPS:en är still, desto bättre mätvärden ger den.

1. För att spara en position (waypoint), tryck på `"MARK"`.

2. Bläddra med pilknappen till namnfältet under `"WAYPOINT"` (där det står `"001"`).

3. Tryck på `"ENTER"` för att börja editera. Använd pilknappen (upp/ned) för att välja bokstäver/siffror och nästa bokstav (höger/vänster). Döp positionen till holkens ID eller något annat meningsfullt. När du skrivit färdigt namnet trycker du `"ENTER"` igen för att sluta editera.

4. **Glöm inte att spara** positionen genom att bläddra med pilknappen till `"SPARA?"` längst ner och tryck på `"ENTER"`.

(Ibland poppar en ruta upp och försvinner: `"MED! TRYCK PAGE."` Trycker man då på `"PAGE"` får man läsa ett meddelande. (T ex att GPS:en har dålig täckning.)

Knapparnas funktioner

GOTO   - Används när man vill gå till en sparad waypoint

☼   - ON/OFF. För att slå av GPS:en, håll inne knappen i 3 sekunder.

QUIT   - Avsluta meny/Tillbaka

Pilknappen - Hoppa mellan olika alternativ på sidan

PAGE   - Nästa sida

MARK - Öppna markera-positionssidan

ENTER - Välj

STONE WALL
FOREST EDGE
WATER

KOHAGELYCKAN