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Abstract

A method for determination of morphometry, sediment distribution, and habitat diversity of lake basins has been evaluated in this work. The basis of the method is that the results of the mapping will be a part of a GIS-application with catchments as delimitation elements. For mapping of lake morphometry, a new instrument was constructed. The instrument combines a digital echo sounder with a DGPS and both are connected to a field computer with real-time GIS-program. An orthophoto is displayed as background on the computer screen and the position of the boat appears as a marker. The DGPS-instrument gives X- and Y-coordinates and the echo sounder gives the Z-coordinates (water depth). At each second these three coordinates are saved in a GIS-database and each saved value is displayed with a marker on the orthophoto. The boat is driven slowly in parallel transects over the lake until the entire image of the lake on the orthophoto is covered with data which are also saved in the database. The combined instrument was also used for mapping the sediment distribution in lakes. The fact that the echo sounder shows different signal patterns for different sediment types was used as a basis for the delineations. The boat is driven in a zigzag manner along a border between two sediment types and at each passage of the border the position is manually saved in a GIS-database. The borders between different habitats were mapped by driving the boat along a border and manually save the boat position. Habitat borders close to the shore, where it was difficult to drive the boat, was mapped correspondingly using a handheld computer connected to a DGPS and walking along the borders. Field data for water depths, sediment- and habitat borders was carried forward to a GIS-program on a desktop computer were the digital maps where constructed. In the GIS-program and in a new Visual Basic-program, a great number of parameters were calculated, e.g. lake area, lake volume, mean water depth, areas for different sediment types, and areas of different habitats.

Sammanfattning

En ny automatisk metod för kartering av sjöars morfometri, sedimentutbredning och vegetationsutbredning har utvecklats. Metoden har utgått från att resultatet av kateringen skall ingå i en GIS-applikation med avrinningsområden som avgränsande enhet. För kartering av sjöns morfometri har ett nytt kombinerat instrument konstruerats där ett digitalt ekolod kombineras med en DGPS och dessa är anslutna till en fältdator med programvara för realtids-GIS. På datorskärmen visas ett ortofoto som bakgrund och båtens possition med en markör. DGPS'n ger X- och Y-koordinat och det digitala ekolodet ger Z-koordinaten (vattendjupet). För varje sekund sparas koordinaterna i en GIS-databas och varje sparat värde visas som en punkt på datorskärmen. Båten körs i långsam hastighet fram och tillbaka över sjön tills dess hela den fria vattenytan täcks med sparade koordinatvärden. För kartering av sjöns sedimentutbredning används samma kombinerade instrument. Ekolodet visar olika signalmönster för olika sedimenttyper. Båten körs i sick-sack rörelse över en gräns mellan två olika sedimenttyper och vid varje passering av gränsen sparas manuellt dess possition. Sjöns vegetationsutbredning karteras genom att båten körs längs en habitatsgräns och possitionen för den sparas manuellt. Habitatsgränser i strandnära lägen där det är omöjligt att framföra en båt karteras på motsvarande sätt med en handburen dator kopplat till en DGPS. Fältdata för vattendjup, sedimentgränser och habitatsgränser överförs till ett GIS-program där de digitala kartorna konstrueras. I GIS-programmet och i ett nykonstruerat Visual Basic-program beräknas ett stort antal parametrar för sjön, t ex vattenarea, vattenvolym, medeldjup, areor för olika sedimenttyper, areor för olika habitat.

Contents

1 Introduction

The Swedish Nuclear Fuel and Waste Management Company (SKB) is responsible for management and disposal of Swedish radioactive waste. The company is planning to construct deep repositories, which will keep the radioactive waste away from the biosphere through hundreds of thousands of years. Two sites have been selected for studies of their suitability for storage of the nuclear waste, Forsmark in the province of Uppland, and Oskarshamn in the province of Småland, both in the southern part of Sweden. Site descriptions will be based on drainage areas and will include the bedrock and overlying geological layers, as well as those terrestrial, wetland, lake, and river ecosystems that potentially may become affected by the installation. Also coastal ecosystems to which the water will drain will be included. One important question to be addressed is: in the case of a leakage from the containers with the nuclear waste, are there any biological processes which in the long-term perspective may lead to an accumulation of radioactive compounds to such an extent that it may become harmful for biota?

The ecosystem studies include a high-resolution documentation and monitoring of the biosphere in catchments that may be affected by a leakage from the repositories. The studies will include more or less natural compartments such as forests, mires, wetlands, lakes, and streams as well as areas affected by man (e.g. agricultural land and urban areas). Regarding lake ecosystems, the basic program includes a variety of morphometry parameters, water and sediment chemistry parameters, and delineation and quantification of the main habitats of the ecosystem /cf. Blomqvist et al, 2000/.

Access to lake morphometry data is an absolute prerequisite for all lake studies included in the site investigation program. The lake morphometry data will, for example, be used to calculate the lake volume, a parameter that in turn is used to calculate the retention time of the water in the lake basin. The latter parameter is a key for understanding the fate of nutrients and pollutants in the system. Furthermore, lake morphometry data are included in the sampling program for chemistry and biology of the open water and used for distribution of samples for sediment characteristics and benthic biota. Depth soundings are normally very time-consuming and have traditionally been performed either 1) manually (and then usually from ice during winter) or 2) automatically, using an echo-sounding equipment which records the water depths along known transects on a paper echogram /e.g. Håkansson 1981/.

To provide detailed knowledge about the sediments in the lake basins, including sediment thickness and volume as well as various chemistry parameters, is another important part of the site investigations. Radionuclides associated to particles, either through adsorption or via incorporation into biota, will most likely end up in the sediments and be accumulated there. Furthermore, the groundwater that enters the lake basin may do so through the sediments, and dissolved radionuclides may be adsorbed to particles during that passage. Hence, there are several reasons to believe that the sediments may constitute a final deposit of radionuclides in the lake ecosystem. Therefore, detailed knowledge about the sediments is an important part of the program.

The habitat diversity of lake ecosystems is a new parameter currently under development of the authors of this report. It describes the area distribution of the five key habitats that can be present in lakes, the pelagic habitat, the profundal habitat, the wind-sheltered (emergent macrophyte-dominated) littoral habitat, the wind-exposed (periphyton-dominated) hard-bottom littoral habitat, and the illuminated soft-bottom littoral habitat /e.g. Blomqvist and

Brunberg, 1999; Blomqvist et al, 2000; Brunberg and Blomqvist, 2000a,b; Carlsson, 2002/. Its use, except for describing the number and area distribution of habitats in the lake, is to create a platform for budget calculations of the metabolism of organic carbon in different parts of the lake ecosystem. In the context of the site investigation program, this is another important parameter, because it will be used to estimate the retention of radionuclides in the lake basin.

In this paper we describe automatic equipment for depth sounding of lakes, using a combination of an echo sounder and a GPS equipment. The equipment can also be used to distinguish different sediment types from each other and to perform most, but not all, measurements of the habitat diversity of the lake ecosystem. Compared to traditional studies of these parameters, the method is time saving and has the advantage that data from the investigations can be directly transferred from the field into GIS (Geographic Information System). We also provide field tests of the equipment in three lakes and one river reservoir. In addition, methods to complete the measurements of the habitat diversity of lake ecosystems are described.

2 Methods

2.1 Mapping of water depths

The field equipment used to map water depths was a digital echo sounder (Simrad EQ32 Mk 11) and a DGPS (Trimble Pro XR) connected to a field computer (Itronix GoBook) using ESRI ArcPad real time GIS software. For each update of the GPS position (each second), the X and Y coordinates were recorded from the GPS together with the Z-value (water depth) from the digital echo sounder. Approximately 3000 depth values per hour were recorded.

An orthophoto (1 meter resolution) was used as background picture in the field computer. Each recorded depth point was displayed on top of the orthophoto. Thereby it became possible to observe which parts of the lake that already had been mapped and this was used as a navigational aid. The target was to record water depths evenly over the lake, i.e. the distance between two points along a transect should not be more than half the distance between two adjacent transects. Since it was possible in the ArcPad program to choose the time interval between recorded water depths, this interval was used to set the traveling time for half the distance between two adjacent transects. The update of the coordinates from the GPS was not fully synchronized with the signal from the echo sounder and this resulted in a maximum time difference of half a second between the signals. With a boat speed of 1 knot this will give accuracy in the recorded coordinates of 0.5 meters. The maximum speed of the boat is therefore limited by the targeted coordinate accuracy.

A calculation example: assume that the maximum acceptable error in coordinates is 10 meters. The DGPS accuracy, measured with a long time series of recordings at a fix point close to the lake, is 5 meters. The maximum error due to boat speed will then be 5 meters. With an acceptable error of 0.5 meters per knot boat speed, the maximum boat speed will be 10 knots. Assuming that the distance between transects is chosen to 50 meters, the time interval between depth recordings along a transect will be 5 seconds if the distance between records along a transect is half of that between transects.

The depth values were imported to the GIS application as a point layer. These values were added to point-values for the shoreline (0 meter water depth). The lake polygon from the digital parcel map was converted from polygon to line, and the line was converted to points evenly spaced along the line. Elevation values from the national digital elevation model (50 meters resolution) close to the water were converted to xyz-values and reclassified to the lake reference level (0 meter at lake surface) and finally added to the point database.

The scattered point depth values were transformed to a regular grid using the Ordinary Kriging interpolation method within the ArcGIS extension Spatial Analyst. Different theoretical semi-variograms were used. All positive values in the grid were then reclassified to a no data code.

2.2 Mapping the bottom sediment type

An echo sounder (Simrad EQ32 Mk 11) with a high frequency (200-kHz) transducer mounted on a small vessel or rubber boat was used for mapping of the sediment type. High-frequency echo sounders have less penetration depth, but higher resolution, than low-frequency echo sounders and can therefore be used to determine the type of bottom substrate. The restricted penetration results in that the high-frequency acoustic signals received will reflect the behavior of the sound waves at the sediment water interface and this behavior in turn reflects the type of sediment hit by the waves /Forsgren et al, 1993/.

The echo sounder was calibrated against a digital bottom sediment map over the Ume River close to the river mouth. The sediment map was displayed in a field computer together with the position of the vessel using the GPS. By traveling across borders of different sediment type, the difference in signals received from different sediment types was observed.

Five characteristics of the echogram were of particular importance for the interpretation of the echogram; roughness of the line surface (even to rough); line thickness (thin to thick with none; diffuse, or distinct shadows), line color (red, green or blue); the occurrence of white line (a line beneath the surface line) and, of a double echo.

The characteristics of the echo-signal from the coarser sediments (hard bottoms) were:

(i) A thin distinct white-line.

(ii) Two or more double-echoes.

(iii) An even and thin surface line.

(iv) A red or yellow color signal dominates on the display.

For the fine-grained sediment (soft bottoms) the corresponding characteristics were:

(i) A lack of a white line.

(ii) Thin to extremely thin echoes.

(iii) At the most one weak double-echo.

(iv) A pink color dominates on the display.

All four characteristics turned out to differ between the two sediment types, and thus, the different sediment types were easily distinguishable.

During measuring water depth, the large-scale sediment distributions were noticed. A more detailed mapping of sediment borders was carried out by slowly traveling along borders in a zigzag movement. Each time the boat crosses a border a point was recorded manually by pressing a save-button. The points were imported to the GIS application and displayed on top of a copy of the lake polygon layer. The single lake polygon was then manually split into a multi polygon sediment layer using the sediment border points. If necessary, the water depth layer was used as help, since sediment borders often coincide with water depth contours. Finally, the sediment polygon layer was converted to a raster format for calculation of parameters related to sediment distribution (see below).

2.3 The habitat diversity of the lakes

The field work to determine the habitat diversity of the lake ecosystem included the following delineations of the borders between key habitats /cf. also Blomqvist et al, 2000/:

a) Measurements of the location of the terrestrial shore line.

b) Measurements of the location of the outer edge of the combined emergent and floating-leafed macrophyte belt.

c) Measurements of the location of the border between course and fine sediments (gravel and sand).

d) Measurements of the location of the border between the litoriprofundal and profundal zones.

Using the information from a), the outer edge of the lake is defined including eventual wetland areas that may encompass the lake. Combining the information from a) with that from b), the area of the emergent and floating-leafed macrophyte-dominated littoral zone can be calculated. Combining a) and c) the area of the near-shore hard-bottom littoral zone can be calculated. Combining b) and c) with d), the area of the submersed littoral zone can be calculated. Using d), the area of the profundal zone can also be calculated. Finally, by calculating the total area of the lake and subtracting the area of the wind-sheltered littoral zone, the area of the pelagic zone can be calculated and so can its volume.

2.3.1 Mapping of the terrestrial shore-line

The equipment used for mapping of the terrestrial shoreline was a DGPS (Garmin 12XL) connected to a PocketPC (Compaq iPaq 3850) with the program ArcPad 6 installed. An orthophoto over the lake was compressed with the MrSid utility in ArcGis 8, and was used as a background picture in the ArcPad. Before mapping in the field, the shoreline on the orthophoto was digitized on screen, the orthophoto was kept as a background, and these two parameters were put into the ArcPad project.

The terrestrial shoreline was then mapped by walking around the lake and points were recorded at approximately every 5 meters. The points were imported to the GIS-application in ArcGis 8 on the desktop PC. The lake polygon digitized from the orthophoto was used as a basis. In cases where the measured terrestrial shoreline and the shoreline from the orthophoto did not coincide, the lake polygon was complemented with polygons by digitizing on the screen using the points in the background.

2.3.2 Mapping of the outer edge of the combined emergent and floating-leafed littoral vegetation zone.

The outer edge of the combined emergent and floating-leafed littoral vegetation zone, respectively, were mapped with the same equipment as for mapping water depths (see above) and the mapping was carried out from a small boat. The GPS antenna was mounted at one side of the boat. The boat was slowly driven along the vegetation border while the field computer recorded points along the line.

The line was imported to the GIS-application on the desktop PC, and converted to polygons.

2.3.3 Mapping of the border between course and fine sediments near the shore

The border between course and fine sediments near the shore was mapped using the same equipment as described for mapping of the bottom sediment type (see 2.2 above).

2.3.4 Mapping of the border between the litoriprofundal and profundal zones

A total of four different methods were employed to determine the border between the litoriprofundal and profundal zones:

a) Light penetration into the water column was measured using a Lambda LI-COR Quantum/Radiometer/Photometer LI-189. The border between the two zones was assumed to be located at the depth where 1% of the radiation at the surface remained.

b) The Secchi disc transparency was measured using a Secchi disc with a diameter of 20 cm. The border between the two zones was assumed to be located at a depth corresponding to two times the Secchi disc transparency.

c) Sediment cores were taken at different depths along a transect from the shore and outwards using a Willner sampler and the uppermost 2–5 centimeters of the sediment were transferred to plastic jars. The sediment samples were homogenized and 1 ml of the slurry was transferred to a plastic tube to which 9 ml of 95% ethanol was also added. The tubes were heated in a water bath at 75°C for 5 minutes and subsequently centrifuged for 5 minutes. The supernatant was analyzed for its concentration of chlorophyll a using a spectrophotometer according to /ISO, 1992/.

d) Sediment cores were taken along a transect from the shore and outwards using a Willner sampler and the uppermost 2–5 centimeters of the sediment were transferred to plastic jars. A subsample of 25 ml was taken and preserved with 25 ml of formalin to a final concentration of formalin of 2%. One ml of this preserved sample was diluted with a mixture of 50% tap water and 50% distilled water to a final volume of 100 or 200 ml. This diluted sample was analyzed under the microscope and the presence of microphytobenthos with intact chloroplasts was noted.

2.3.5 Further subdivision of the emergent macrophyte littoral habitat

Due to the delay caused by the problems with the combined GPS and echo sounder equipment further studies of the emergent macrophyte littoral habitat were also performed. As defined in 2.3 (above) the emergent macrophyte littoral habitat includes the wetland zone surrounding the lake as well as the emergent and floating-leafed littoral zones within the lake. After the measurements of the terrestrial shoreline and the outer edge of the combined emergent and floating-leafed littoral zone had been completed, a further subdivision of the emergent macrophyte littoral habitat was performed as follows:

The shoreline, i.e. the border between the wetland zone and the combined emergent and floating-leafed vegetation zone was mapped with the same equipment as for the terrestrial shoreline. Using this border, a multi-polygon layer with the wetland shoreline and the terrestrial shoreline was created. The polygons between the shoreline and the terrestrial shoreline were then divided into smaller polygons based on the wetland vegetation type by walking along vegetation borders. The polygon attributes were updated manually each time a new polygon was created.

To separate different sub-zones (i.e. emergent and floating-leafed vegetation), the GIS-application in the field computer was prepared with lines for different vegetation border types, and an appropriate line type was chosen for each new measurement. The lines were imported to the GIS-application on the desktop PC, and converted to polygons. The vegetation polygon layers from the wetland zone was merged with the vegetation polygon layer from the littoral vegetation zones, and used to build up a complete vegetation map.

2.4 Calculations of parameters for lakes and catchments

A program, written in Visual Basic was used for calculation of morphometry and other parameters for lakes and catchments. Inputs to the program were:

(i) A digital elevation model (DEM) for the lake with negative values for water depths and positive values for land heights (reference level 0). The DEM was formatted in ArcInfo ASCII-grid format and the values were given in meter units.

(ii) A DEM for the catchment with the sea level as reference level. The DEM was formatted in ArcInfo ASCII-grid format and the values were given in meter units.

(iii) A categorical raster map for vegetation distributions in the lake with numerical codes for each vegetation type (10 classes) and with the same cell size and extension as the DEM for the lake.

(iv) A categorical raster map for sediment distributions in the lake with numerical codes for each sediment type and with the same cell size and extension as used for the DEM for the lake.

(v) A categorical raster map for land use in the catchment with numerical codes for each land use type (7 classes) and with the same cell size and extension as the DEM for the catchment.

(vi) Values for specific runoff in $dm^3\ s^{-1}\ km^{-2}$.

The output from the program is a list in the form of a text file with in total 41 parameters describing the lake and its catchment.

The following parameters were calculated for the lake:

1 Total lake area (A, km^2).

2 Maximum length (L, m), the longest straight line over the water surface /Håkansson, 1981/.

3 Maximum width (W, m), the longest straight line perpendicular to the length line.

4 Mean water depth ($Z_{Mean,}$ m).

5 Maximum water depth (Z_{Max}, m).

6 Lake volume (V, m^3).

7 The dynamic sediment ratio (DSR) as the square rot of the area divided by the mean depth /Håkanson and Jansson, 1983/.

8 The depth ratio (DR) as the mean depth divided by the maximum depth /Neuman, 1959/.

9 The volume development (D_v) as the ratio of lake volume to a cone of basal area equal to the surface area of the lake, and height equal to the maximum depth of the lake /Timms, 1992/.

10 Relative depth ratio (Z_r, %) as the ratio of maximum depth to mean diameter represented by the square root of the lake area.

11 Shore length (SL, m).

12 Shoreline development factor (D) as shore length divided by circumference of a circle with an area equal to that of the lake.

13 Mean discharge (Q, $m^3 s^{-1}$).

14 Theoretical water residence time (WRT, days).

15 Share of soft bottoms (SB, %).

16 Share of hard bottoms (HB, %).

17 Share of sunlit bottoms (SLB, %).

18 Share of sunlit soft bottoms (SLSB, %).

19 Share of open water (OW%).

20 Share of bog (B%).

21 Share of mire (M%).

22 Share of swamp (S%).

23 Share of alder fen.

24 Share of *Phragmites*-dominated littoral.

25 Share of floating-leafed vegetation littoral.

The following parameters were calculated for the catchment:

26 Area (CA, km^2).

27 Length (CL, km), horizontal distance along the longest dimension of the catchment.

28 Perimeter (P, km).

29 Form factor (F) as perimeter divided by circumference of a circle with an area equal to that of the catchment.

30 Maximum elevation (E_{Max}, masl).

31 Minimum elevation (E_{Min}, masl).

32 Elevation difference (E_{Diff}, m).

33 Mean basin relief (H_{Mean}, %) as elevation difference divided by the square rot of catchment area.

34 Relief ratio (R_h) as mean basin relief divided by catchment length.

35 Share of lake area (L%).

36 Share of forested area (F%).

37 Share of arable land (A%).

38 Share of open land (O%).

39 Share of cutting area (C%).

40 Share of wetlands (W%).

41 Share of rocks (R%).

An option in the program is to export values for constructing a relative hypsographic curve. The output is a comma separated text file with values for water depth and percentage of relative area for 100 different depths. The text file can be imported to Excel and graphs can be made in that program.

3 Results from applications of the methods in three lakes and one river reservoir

3.1 Measurements of water depths

The first set of measurements of water depths in Lakes Ramsen, Tvigölingen, and Eckarfjärden turned out to be slightly incorrect, at least when compared to existing depth data from the two lakes /Brunberg and Blomqvist, 1998/. Also the measurements in the Stornorrfors Reservoir (Figure 3-1) deviated from what was already known about the morphometry of the river basin before construction of the dam. After a thorough and time-consuming investigation of the combined instrument, an error in the system was encountered. The error consisted of a time lag between the output of signals from the GPS and the digital echo sounder. As a result, the depth values were coupled to the wrong X, Y-coordinates from the GPS instrument. After the error had been corrected (see below), the measurements functioned well and a reasonable depth chart of Stornorrfors reservoir could be obtained (Figure 3-2).

After correction of the error in the combined GPS and echo sounder instrument the equipment was tested again in the shallow Lake Eckarfjärden in the Forsmark area. The measured depths (yellow points in Figure 3-3) were added with the terrestrial shoreline converted to points and with depths set to zero (red points in Figure 3-3). Elevation data from the area close to the lake from the SKB 10 meter resolution DEM were converted to a reference level of zero at the lake surface and added to the data set (green points in Figure 3-3).

Using this combined elevation data set, a regular depth grid was created in ArcGis Spatial Analyst extension. The grid resolution was set to 10 meters (Figure 3-4).

The depth grid was then used to create depth contours for the lake (Figure 3-5).

The depth grid was used as input to the Visual Basic program for calculation of lake specific parameters for Lake Eckarfjärden and the results are presented in Table 3-1.

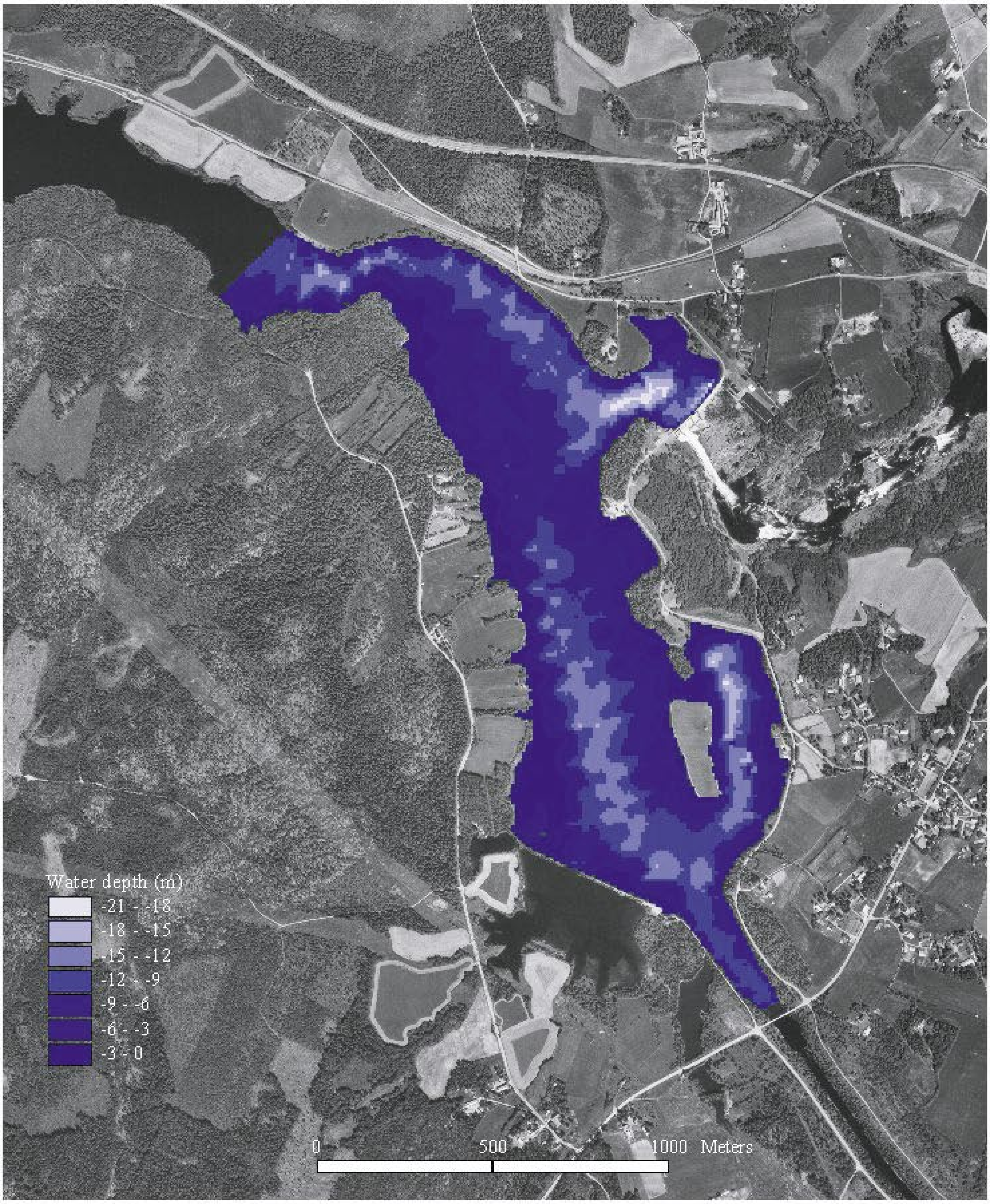


Figure 3-1. *Results from depth measurements in the Stornorrfors reservoir in River Umeälven before correction of the error in the instrument.*

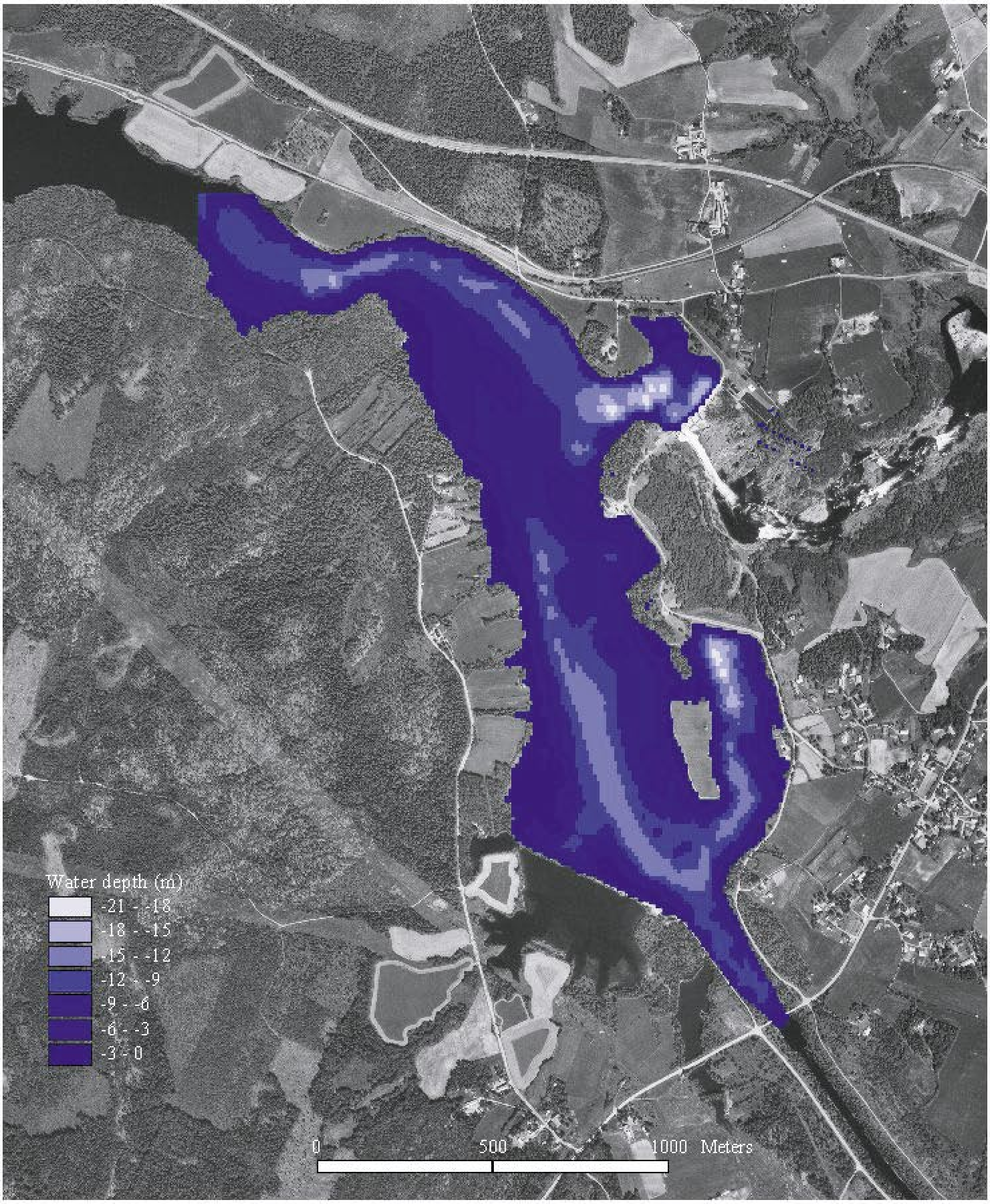


Figure 3-2. *Results from depth measurements in the Stornorrfors reservoir in River Umeälven after correction of the error in the instrument.*

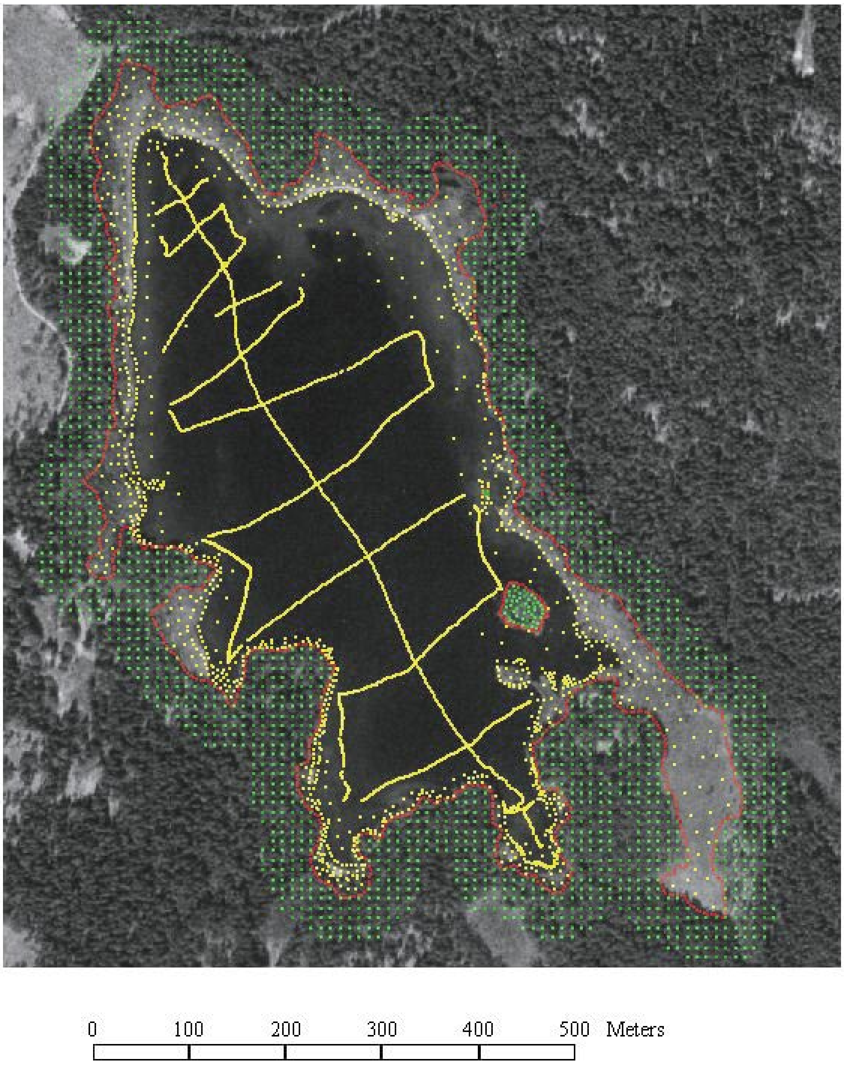


Figure 3-3. *Elevation point values used for interpolation of a depth grid for Lake Eckarfjärden.*

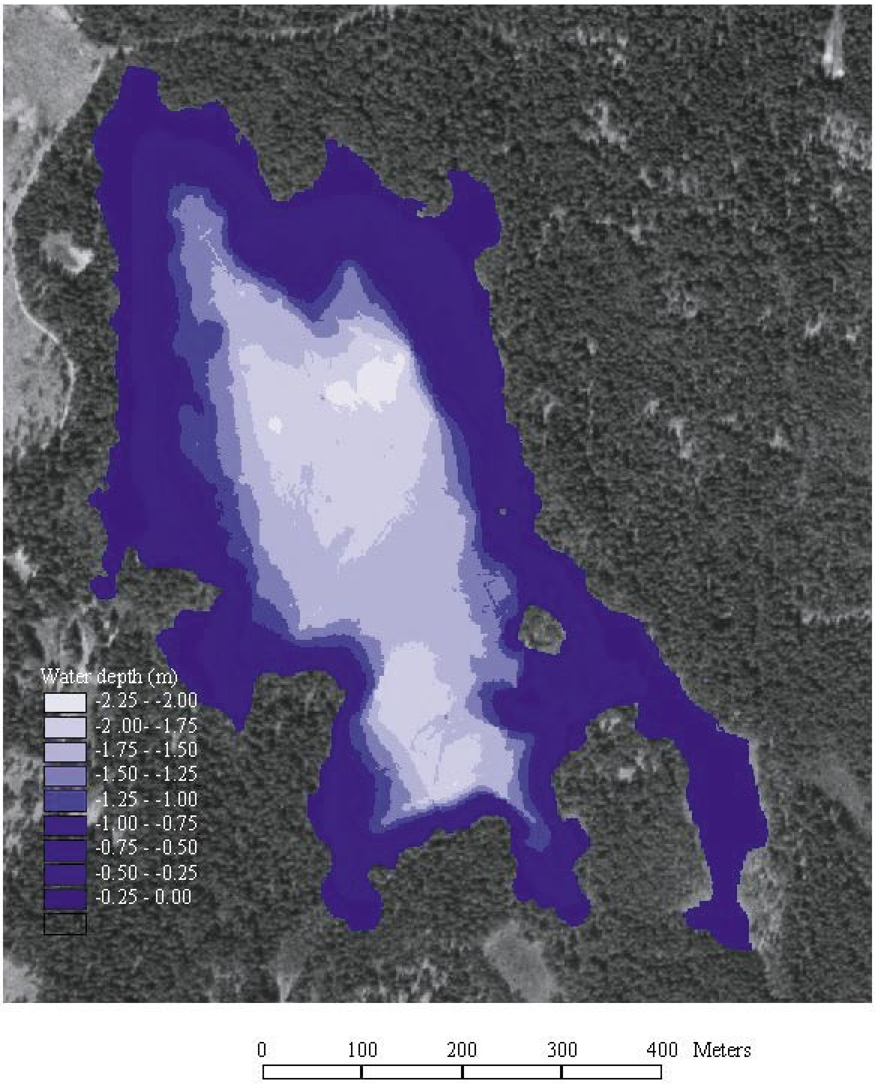


Figure 3-4. *The depth grid for Lake Eckarfjärden.*

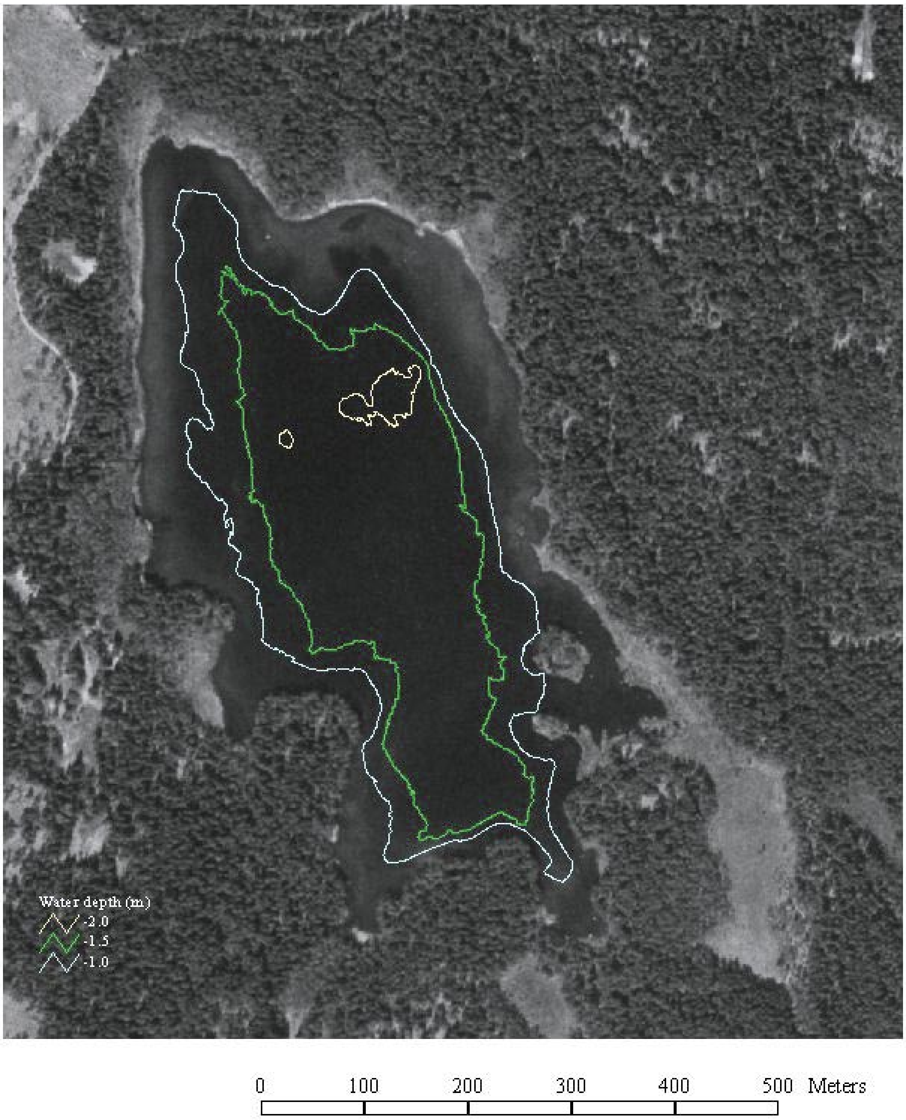


Figure 3-5. Depth contours for the Lake Eckarfjärden.

Table 3-1. Lake specific parameters for Lake Eckarfjärden.

Parameter	
Total lake area (A, km^2)	0.28
Maximum length (L, m)	1007
Maximum width (W, m)	410
Mean water depth ($Z_{Mean,}$ m)	0.91
Maximum water depth (Z_{Max}, m)	2.12
Lake volume (V, m^3 10^6)	0.257
The dynamic sediment ratio (DSR)	0.58
The depth ratio (DR)	0.43
Relative depth ratio (Z_r, %)	4.99
Shore length (SL, m)	4400
Shoreline development factor (D)	2.34
Mean discharge (Q, m^3 s^{-1})	0.009
Theoretical water residence time (WRT, days)	328

3.1.1 Description and correction of the error in the combined GPS and echo-sounder instrument

The error encountered in the instrument was due to an overload in a buffer memory in a NMEA (National marine electronics association) -mixer. The NMEA-signals from the echo sounder and from the GPS are mixed in this mixer before they are sent to the real-time GIS program in the field computer. The mixer is equipped with a small buffer memory to store the first signal for a short time in order to synchronize with the later signal. The Trimble GPS is able to send 7 different types of NMEA-signals, including e.g. position, how many satellites that are used in the calculation of the positions, the quality of the signals from each satellite. The Simrad echo sounder sends 5 different NMEA-signals, including e.g. depth below water surface, depth below the keel, boat speed over ground. In cases when all options for NMEA-output were activated both in the GPS and in the echo sounder, the memory buffer in the NMEA-mixer was not large enough to store the signals and a memory overflow occurred. As a result, there was a bad synchronization between the signals that led to that the time for measuring water depth differed from the positioning time.

In order to get an accurate synchronization of the signals, the NMEA-output from both the echo sounder and the GPS had to be limited to approximately 4 NMEA-signals and this adjustment was made. The NMEA-signal from the echo sounder for water depth below water surface is required (NMEA code DBS), as well as the NMEA-signal for position from the GPS (NMEA code GLL).

In the Simrad EQ32 MK II echo sounder, the NMEA-outputs are activated/deactivated by:

(i) press the MENU button,

(ii) move the marker to “Interface setup remote” and press ENT,

(iii) set DBS ON and all other NMEA-outputs to OFF by pressing +/– buttons,

(iv) press ENT.

Then set the offset distance, i.e. the distance between the water surface and the transducer by:

(v) press the MENU button,

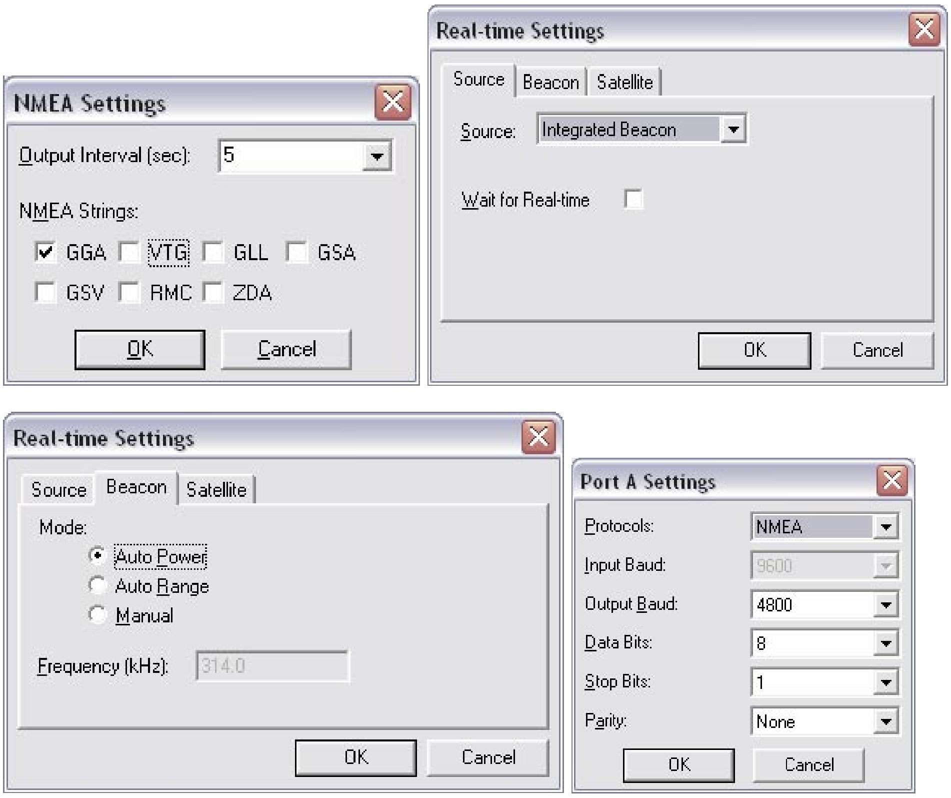
(vi) move the marker to “Ekolod-inställning”,

(vii) set “Svängarens djup under ytan:” to a appropriate value in meter unit,

(viii) press ENT.

In Trimble Pro XR GPS receiver, using the software GPS Pathfinder Controller version 1.30 sets the NMEA-output. The software is downloadable for free on the Trimble home page (http://www.trimble.com). Connect the GPS to the PC with a serial cable. Start the program and set parameters according to Figure 3-6.

It is important that the communication port on the field computer is correctly configured in order to receive the NMEA-signal from the mixer. With the program HyperTerminal (often placed in *Program>Assessories>Communications*) a file is created where COM1 is chosen and in the drop-down menu *Port Settings* the communication parameters are set to values according to Figure 3-7. When the file is opened in the HyperTerminal the port is opened with these communication parameters.



Output Interval (sec): 5

NMEA Strings:

☑ GGA ☐ VTG ☐ GLL ☐ GSA
☐ GSV ☐ RMC ☐ ZDA

Source: Integrated Beacon

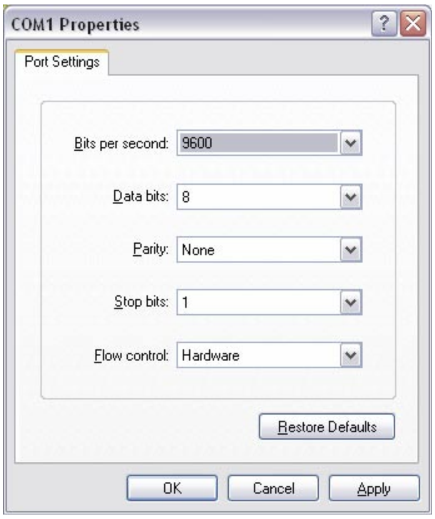
Wait for Real-time ☐

Mode:
● Auto Power
○ Auto Range
○ Manual

Frequency (kHz): 314.0

Protocols: NMEA
Input Baud: 9600
Output Baud: 4800
Data Bits: 8
Stop Bits: 1
Parity: None

Figure 3-6. *NMEA-settings in the GPS Pathfinder Controller program.*



Bits per second: 9600
Data bits: 8
Parity: None
Stop bits: 1
Flow control: Hardware

Figure 3-7. *Port settings in the HyperTerminal.*

Another problem is that the field computer touch screen performs unexpected when wet, e.g. a simple touch is interpreted as a double touch. An umbrella must protect the field computer during rainy conditions.

3.2 Mapping sediment distribution

The sediments of the Stornorrfors reservoir and Lake Ramsen were mapped using the combined instrument. In both cases, it was possible to use the instrument to distinguish between soft and harder types of sediments, but in Lake Ramsen there was a problem with rocky bottoms of considerable slope along the W side.

The echo sounding of the Stornorrfors reservoir was carried out in July 2001 along transects N-S and W-E directions with a distance of approximately 100 meters between individual transects. Only two different sediment types were observed (Figure 3-8):

(i) Coarse sand or coarser grains (> 0.5 mm).

(ii) Medium sand or finer grains (< 0.5 mm).

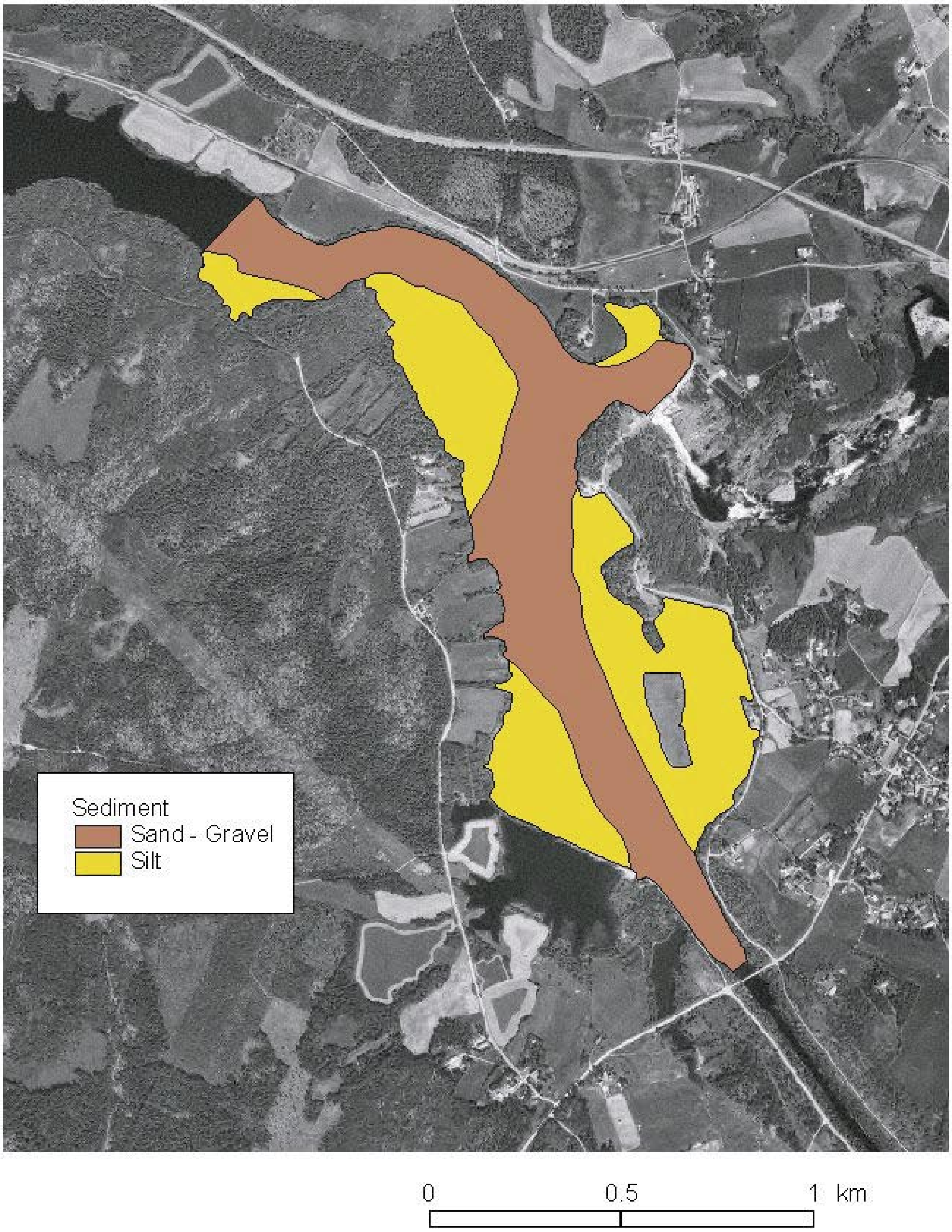


Figure 3-8. *Sediment distribution in the Stornorrfors reservoir.*

The echo-sounding of Lake Ramsen was carried out in August 2001 and approximately 400 points was recorded along borders with different sediment types. In this lake 2 different types of bottom substrates were found (Figure 3-9). Fine sediments were found where the water depth was greater than approximately 5 meters, except along the west side of the lake where the naked rock extended down to 11 meters. Hard bottoms were found especially along the east side of the lake, but in most areas that were free of vegetation, the bottom was stony.

During mapping of the sediment distribution in Lake Ramsen, there was a problem to receive signals that made it possible to distinguish between the extremely steep bare rock bottom along the west side and other bottom types. The reason for this is most likely that steep bottoms do not reflect the signals back to the receiver in a straight line but instead scatters the signals in many directions. As a result, the echo received by the instrument rather resembles that of a softer kind of bottom than that of solid rock. Changing the settings for the echo sounder, such as changing the frequency or pulse length, can not solve the problem, which merits further investigation.

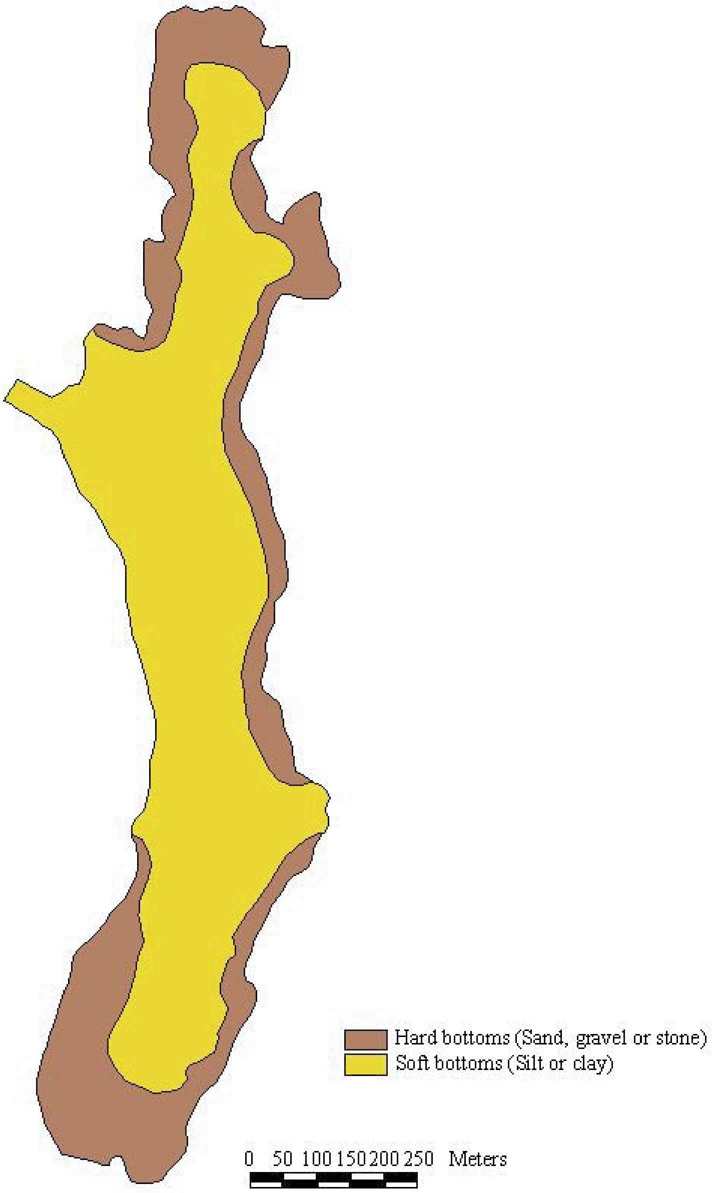


Figure 3-9. *Sediment distribution in Lake Ramsen.*

3.3 Delineation of different key habitats in the lake and main types of vegetation at the lake-wetland interface

3.3.1 The habitat delineation methodology

/Carlsson, 2002/ tested the new habitat delineation method in three lakes of different limnological character as a MSc-project at Uppsala University. Her main findings regarding the new methodology were:

Mapping the terrestrial shoreline

The equipment for mapping terrestrial shoreline did not prove satisfactory. The handheld computer (Compaq iPaq) was not working at all in bad weather conditions, e.g. in air temperatures below zero, in air with high moisture content, or under rainy conditions. Furthermore, the display was also difficult to read under sunny conditions.

During bad weather conditions, the computer was shutting down after approximately one hour of use and had to be warmed up and dried before it became possible to start again. All sampled records were lost after such a “crash”. Three different items of the Compaq iPaq were tested with the same bad result.

The field computer could not replace the handheld computer due to its weight, so in the future, the Trimble TSCe field computer will replace the Compaq iPaq. The Trimble equipment is rugged and certified to work under bad weather conditions.

During good weather conditions the equipment gave satisfactory results.

Mapping the outer edge of the combined emergent and floating-leafed macrophyte zone

The proposed methodology worked excellently. Because the measurements were carried out using the combined echo sounder and GPS equipment it was also possible to get an estimate of the water depth at the edge of the emergent and floating-leafed macrophyte belt.

Mapping of the border between course and fine sediments near the shore

Using the combined echo sounder and GPS equipment made it possible to distinguish the border between sandy and silty sediments in most parts of Lake Ramsen, which was the only locality in which a near-shore hard-bottom habitat was encountered. However, as presented under 3.2 (above), the instrument failed to identify naked rock along the W shore of this lake, most likely because the steep slope of this bottom scattered the signal from the instrument. The problem was solved by manual sounding using a metal sediment sampler which made a noise detectable by ear in the boat as it did hit the rocky bottom. Surprisingly, the rock was found to extend down to more than 10 meters depth in this small (area 40.4 ha) lake which has a maximum depth of 11.5 meters. Hence, the proposed methodology did not prove to work satisfactorily and there is a need for a new definition of the near-shore hard-bottom habitat (see discussion below).

Mapping of the border between the litoriprofundal and profundal zones

Three of the four methods employed to measure the border between the litoriprofundal and profundal zones in the lakes turned out to work satisfactorily: light penetration, Secchi disc transparency, and microscopic examination of microphytobenthos in sediment samples. In

Lake Tvigölingen, the light penetration measurements indicated that 1% of the radiation at the surface remained at a depth of 1.2 meters, the Secchi disc transparency was measured to 0.45 meters indicating that the border was located at 0.9 meters. These two findings were verified by the microscopic analysis which revealed that microphytobenthos with intact chloroplasts existed down to a depth of 1 meter. In Lake Ramsen, 1% of the surface light remained at 5 meters depth, double the Secchi disc transparency was 4.8 meters, and living microphytobenthos were found down to 5 meters. In the third lake, Eckarfjärden, all three measurements indicated that the littoral zone covered the entire bottom area of the lake.

The measurements of chlorophyll a turned out to be of little use for the determination of the border between the litoriprofundal and profundal zones. In Lakes Tvigölingen and Ramsen, which both contained substantial profundal zones, the concentrations of chlorophyll were high also at depths far below the border indicated by the other methods. The reason, as evidenced by the microscopic analysis, was that sediment samples from all depths contained large amounts of phytoplankton lost from the pelagic zone via sedimentation.

3.3.2 The habitat distribution in Lakes Tvigölingen, Eckarfjärden and Ramsen

/Carlsson, 2002/ also calculated the habitat distribution in the three lakes surveyed. Despite the methodological problems described above, the results clearly reflect the different limnological character of the systems (Figures 3-10, 3-11, and 3-12). The ecosystem in Lake Tvigölingen, a heavily stained brownwater lake, is dominated by the pelagic and profundal zones, while the emergent macrophyte littoral habitat covers a smaller portion of the system, and litoriprofundal and near-shore hard-bottom habitats are completely lacking (Table 4-1). In contrast, the ecosystem of the oligotrophic hardwater Lake Eckarfjärden is dominated by the pelagic and litoriprofundal habitats, the emergent macrophyte littoral zone covers a smaller portion of the system, and profundal and near-shore hard-bottom habitats are lacking (Table 4-1). Lake Ramsen showed the highest habitat diversity of the systems with all five key habitats represented (Table 4-1). In this lake, the pelagic habitat dominated, followed by the profundal habitat, the littoriprofundal habitat, the emergent macrophyte littoral habitat, and the near-shore hard-bottom habitat. /Blomqvist, 2002/ used these area data to calculate the habitat diversity index (HI) for each system using the formula for calculation of the Shannon-Weaver diversity index /Shannon and Weaver, 1949/. The results of these calculations show that the most diverse lake in terms of number of key habitats, Lake Ramsen, also showed the highest diversity index (Table 4-1). The difference in habitat index between Lake Tvigölingen and Lake Eckarfjärden were small.

Table 4-1. Area distribution of different key habitats and habitat index (HI) Habitat index for three lakes in the province of Uppland, Sweden. Habitat 1: The emergent macrophyte littoral habitat. Habitat 2: The near-shore hard-bottom habitat. Habitat 3: The littoriprofundal habitat. Habitat 4: The profundal habitat. Habitat 5: The pelagic habitat Habitat areas (projection areas) are given in km^2.

Habitat	1	2	3	4	5	HI
Tvigölingen	0,022	0	0	0,050	0.050	1,5
Eckarfjärden	0,058	0	0,174	0	0,174	1,45
Ramsen	0,044	0,008	0,093	0,259	0,360	1,72

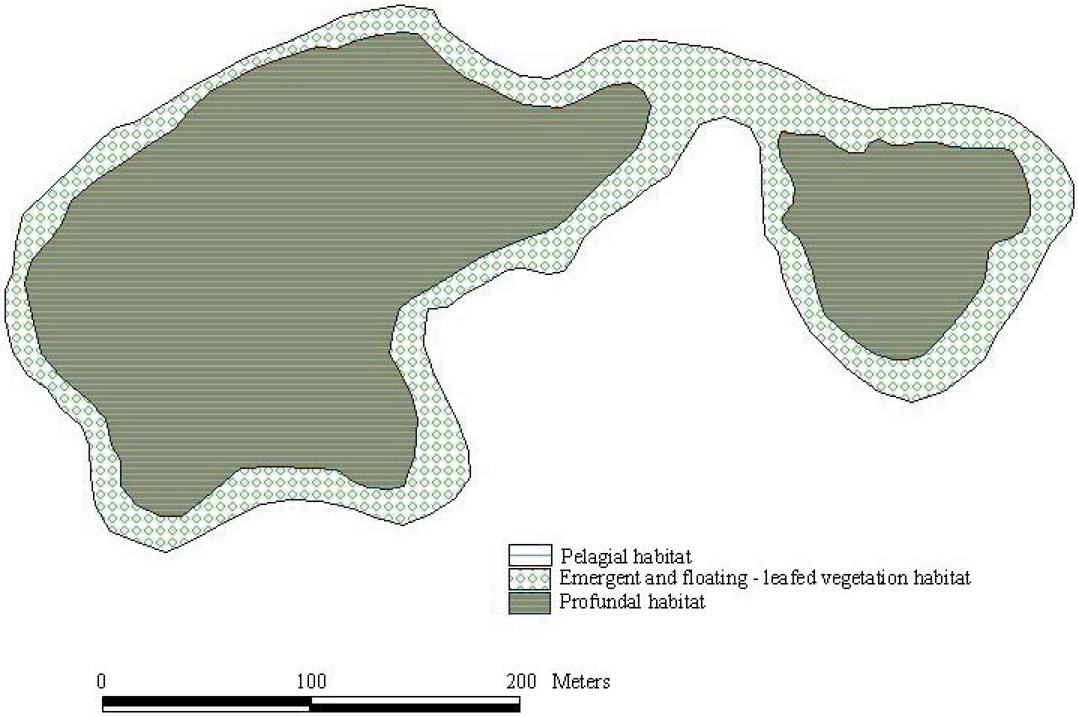


Figure 3-10. *Habitat distribution in Lake Tvigölingen 2001. Modified from Carlsson 2002. The area of the profundal habitat coincides with that of the pelagic habitat.*

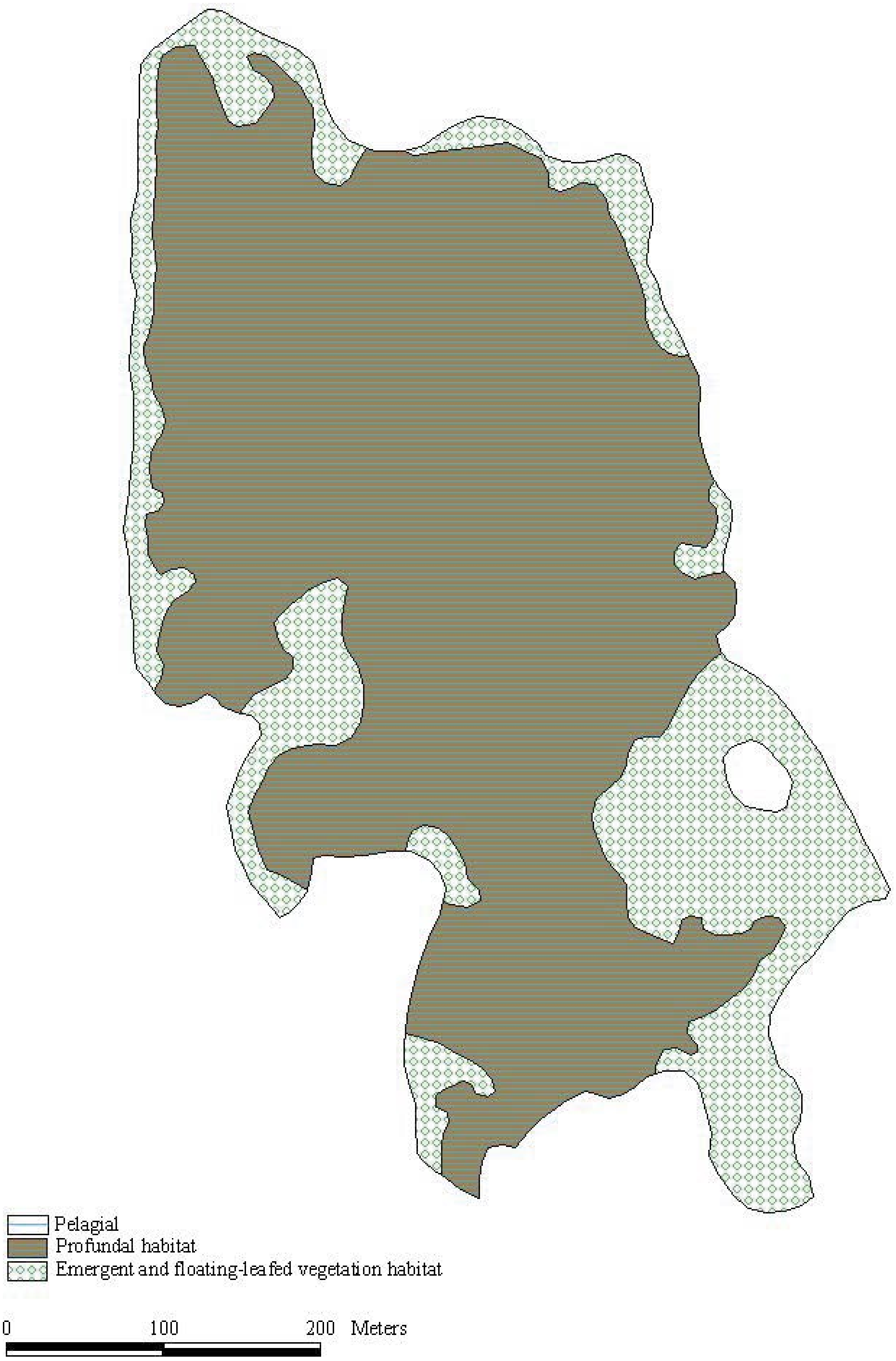


Figure 3-11. *Habitat distribution in Lake Eckarfjärden 2001. Modified from Carlsson 2002. The area of the litoriprofundal habitat coincides with that of the pelagic habitat.*

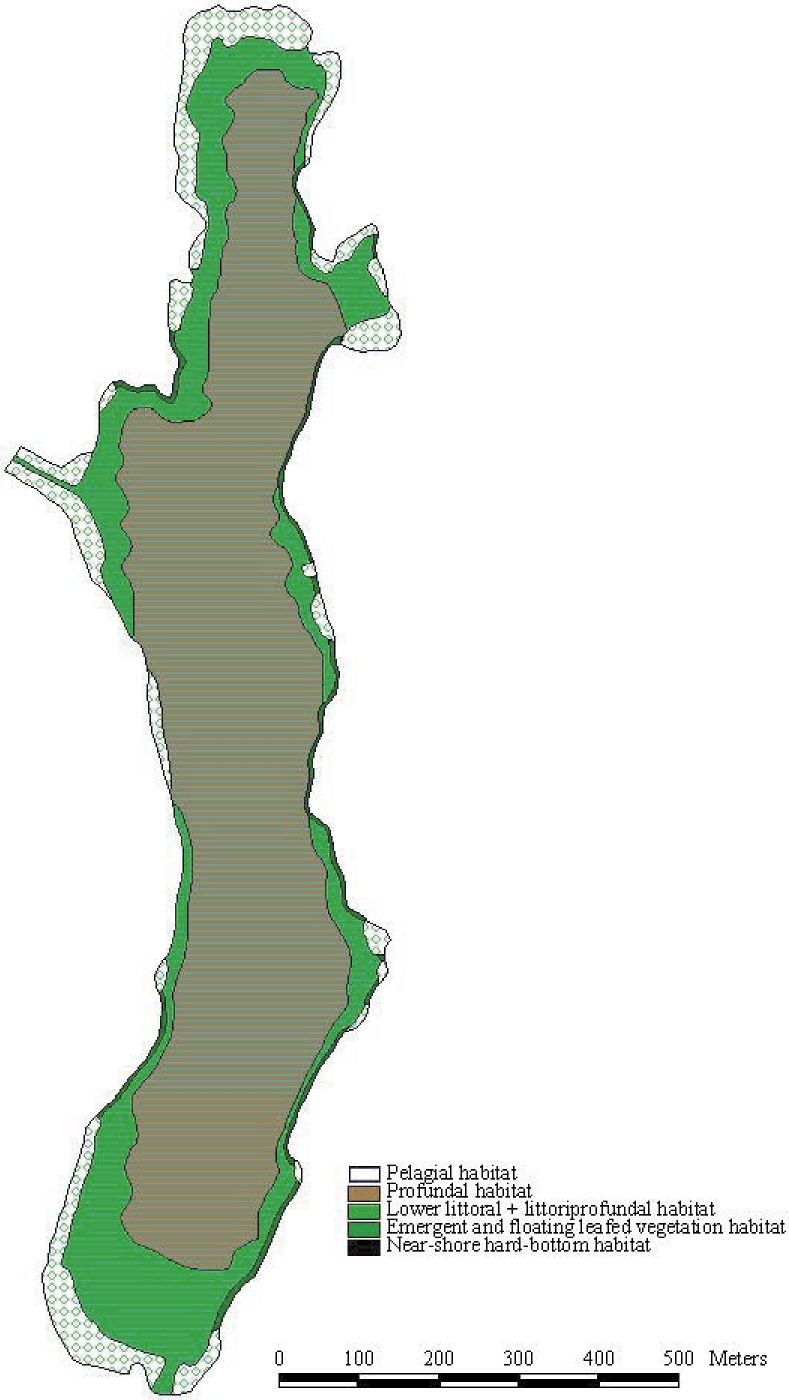


Figure 3-12. *Habitat distribution in Lake Ramsen 2001. Modified from Carlsson 2002. The pelagic habitat overlies the profundal, litoriprofundal, and near-shore hard-bottom habitats.*

3.3.3 Further subdivision of the emergent macrophyte littoral habitat

The mapping of the more detailed composition of the emergent macrophyte littoral habitat in Lake Eckarfjärden was carried out within the framework of the ongoing site investigation program in the Forsmark area in which the authors of this report participate. The study included determination of the border between the wetland encompassing the lake and the border between different functional groups of macrophytes. The results show that such a subdivision – at least technically speaking – is easy to make with the GPS-equipment and will increase the resolution between habitats considerably. However, finding and following in particular the border between the wetland and the emergent macrophyte part of the habitat includes many practical problems including walking among dense macrophyte stands. Hence, the costs for this increase in resolution may be considerable.

4 Discussion

After determination of the error, the new instrument combining a digital echo sounder and a GPS-equipment is working satisfactorily. The instrument can be used to measure water depths of lakes very rapidly compared to traditional methods, and parameters calculated from water depths are also more reliable compared to traditional methods.

The new instrument can also be used to determine sediment type in many, but not all, aquatic system. As mentioned earlier, it was difficult to detect steep sloping bare rock surfaces since the signals are scattered in many directions. One way to solve the problem, which merits further testing, may be to calculate the bottom slope from the water depth raster map, and specify a condition that soft bottoms cannot be found on step slopes.

During validation of the method, the goal was to distinguish soft bottoms from hard bottoms and the echo sounder signals was found different for all four characteristics between these bottom types. This indicates that it is possible to do a further division of the bottom types and still receive unique combinations of signal attributes. However, this requires a more accurate validation with an extensive sediment sampling for calibration of the instrument.

With respect to the proposed new methodology to determine the habitat diversity of the lake ecosystem, the new instrument, together with the hand-held GPS, can be used to determine several, but not all, of the borders between key habitats in the lake ecosystem. Hence, the location of the terrestrial shore-line can without any technical problems be determined by walking along the border of the lake using the hand-held GPS. Because it involves walking in an ecotone often dominated by shrub, this proved to be the most time-consuming border to determine. Depending on the aim of the study an alternative would be to delineate this border directly on area photographs, e.g. the orthophoto used as a basis for the measurements. Determination of the outer edge of the combined emergent macrophyte and floating-leafed littoral zone proved to be very easy with the new instrument. Furthermore, since the instrument also records water depth, another valuable piece of information can be obtained as a spin-off effect of the measurements. When the water depth at this border is known, the volume of water in the habitat can be calculated and so can the volume of the pelagic zone. Since the emergent macrophyte and floating leafed littoral zone is currently believed to act as a wetland filter for nutrients and carbon entering lake ecosystems /e.g. Wetzel, 2001/, knowledge about the actual morphometry and volume of this filter may be of great value in many types of lake investigations.The most difficult border to determine was that of the outer edge of the near-shore hard-bottom habitat. We expected this habitat to be present only in larger lakes and principally induced by wave action. However, from the investigations in Lake Ramsen, it is evident that such a macrophyte-free habitat also exists in smaller lakes with shores of a steep morphometry and in lakes in which the bottom is dominated by bedrock. In such lakes, where the hard-bottoms are not induced by wave action, the fauna and flora in this habitat will not show the special adaptations to stay in the habitat as found in more wind-exposed hard-bottom habitats. Nevertheless, since the vegetation-free zone in smaller lakes is not likely to function as such an efficient biological filter for incoming nutrients as the emergent and floating-leafed macrophyte zone it may still be wise to separate these two types of near-shore littoral habitats. A problem is then to find the outer edge of the hard-bottom habitat. /Carlsson, 2002/ solved this problem by setting the border to the same depth as that of the average depth of the edge of the emergent and floating leafed macrophyte littoral zone and we suggest that this is done also in future investigations. Whether or not the new combined instrument can be used to determine the outer edge of the true, wave-induced, nearshore hard-bottom littoral zone remains to be tested in larger lakes. However, from the tests of the instrument regarding its ability to distinguish different types of sediment, is seems quite possible to determine the location of that border. With the outer limits of the emergent and floating-leafed, and near-shore hard-bottom, littoral habitats defined, the area of the litoriprofundal zone can be determined as soon as its border to the deeper, profundal zone has been defined. In this case the new combined instrument is of little help, since the border is defined by the presence/absence of photosynthetic plants. We emplyed four methods to determine this border of which three turned out to be of use: measurements of the depth where 1% of the radiation at the surface remaines, measurements of the depth corresponding to two times the Secchi disc transparency, and microscopic examination of the presence/absence of microphytobenthos with intact chloroplasts on the sediment. The fourth method, determination of the chlorophyll content of surface sediments can not be used, due to the presence of large amounts of settled phytoplankton all over the lake bottom. To determine this border between the litoriprofundal and profundal habitats we suggest a combination of two of the methods. starting with measurements of the light penetration (or double Secchi disc depth) followed by sediment sampling and microscopic determination of microphytbenthos at sediment depths near the indicated location from the light measurements. After this has been completed, calculations of the area of all five major habitats in the lake ecosystems is possible and these areas can then serve as a basis for planning of sampling of biota and for carbon budget calculations.

The terminology for the different key habitats proposed in this paper is complicated and needs to be further discussed here. The names pelagic and profundal zones are well established and should therefore be used and so is the name littoral zone. However, naming the three sub-habitats of the littoral zone is more complicated. One reason is the discovery that near-shore hard-bottom zones may be determined by other factors than wind-exposure and another is that the border between the inner macrophyte-dominated zone and the deeper litoriprofundal zone was set to the outer edge of the combined emergent macrophyte and floating-leafed littoral zone. This means that the relatively well established names wind-exposed littoral zone, wind-sheltered littoral zone, and littoriprofundal zone, respectively, do not apply in a more strict sense. Nevertheless, the delineation of these habitats is from practical and theoretical points of view highly reasonable, as the habitats represent very different functional units in the lake ecosystem. /Blomqvist, 2002/ discussed this matter and suggested the following names to be used:

Pelagial habitat

Profundal habitat

Littoral – helophyte and floating-leafed vegetation habitat

Littoral – near-shore hard-bottom habitat

Littoral – submersed vegetation habitat

Altogether, by using a combination of a digital echo sounder, a DGPS and a field computer with a real-time GIS program, mapping of water depth, sediment distribution and vegetation can be done faster and with higher accuracy compared to traditional methods. Furthermore, the data captured in the field has formats that are prepared for import to the GIS-program on the desktop computer, so the GIS-application is build up without any time-consuming data format conversions or change in coordinate system or map projections. Using the Visual Basic program for calculation of lake and lake related parameters means that no subjective manual measurements in the digital maps are needed, so the accuracy in the calculations becomes higher compared to traditional methods. With the proposed alterations, the new method for delineation of key habitats in the lake ecosystem will most likely work satisfactorily. Some of the problems encountered needs further testing, but this can be made by applying the method in more lake basins, including those covered by the site investigations carried out by SKB.

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