Proc. Estonian Acad. Sci. Biol. Ecol., 2007, **56**, 1, 33–46
https://doi.org/10.3176/eco.2007.1.03

Variability of optical water types in Lake Peipsi

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Received 27 January 2006, in revised form 27 October 2006

Abstract. Lake Peipsi is a large freshwater lake that needs regular and careful monitoring. Remote sensing could be a powerful tool for this purpose; however, the standard ocean colour products often fail over optically complex waters. A three-year intensive study of optically active substances and reflectance was carried out in L. Peipsi. We determined that the lake's water most commonly belonged into *Moderate* (65%) type, followed by *Turbid* (16%) and *Clear* (9%) types; only 5% of the samples were classified into *Very turbid* and *Brown* types. Because water types vary in time and space, there is a need for a comprehensive approach to the optical classification of water types, which could automatically be applied to satellite image. Despite the differences in optically active substances, reflectance spectra in *Moderate* and *Turbid* types cannot be distinguished by the standard processing scheme of the MODIS sensor because of its lack of suitable bands.

Key words: optical properties, turbid lake, remote sensing.

INTRODUCTION

The availability of remotely sensed ocean colour data from satellite sensors such as MERIS, MODIS, and SeaWiFS has opened up new perspectives in the study of the spatial and temporal variability of water quality distributions in coastal waters as well as in large inland waterbodies. Full exploitation of ocean colour imagery requires developments in the modelling of optical properties in the upper water layer of the ocean and their relationships with biological, physical, and chemical parameters. Particularly in coastal and inland waters, both inherent and apparent optical properties are influenced by a wide array of processes, which are forced by climatic conditions and human impact.

Classification of water types helps to clarify relationships between different properties inside a certain class and quantify variation between the classes. Optical water type classification approaches, based on remotely sensed water-leaving radiance, have a great potential to contribute to the study of spatial and temporal dynamics of ecologically and biogeochemically important properties of natural

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waters. Additional information, such as in situ observations, can be used to categorize the water types in some ecologically relevant manner (Martin Traykovski & Sosik, 1998). It was demonstrated by case studies in the stirred shelf sea that tuning satellite remote sensing algorithms by water type greatly improves product retrieval (A. Cunningham & A. Dudek, pers. comm.).

Unfortunately, there are no general standards for classification. Initially, Morel & Prieur (1977) classified water masses simply as Case 1 or Case 2, based on their spectral reflectance and attenuation. In Case 1 waters, variations in colour are dominated by phytoplankton and its associated degradation products. In coastal and inland waters, various processes can lead to large optical variability that may be independent of the abundance of phytoplankton pigments. Absorption by phytoplankton, detritus, and coloured dissolved organic matter (CDOM) can be used to classify the so-called Case 2 waters (Mobley, 1994). However, concentrations of optically active substances (OAS: phytoplankton pigments, suspended mineral particles, and CDOM) in small bays and lakes may be so high that they exceed the limits of classifications based on field data from the seas and oceans. Preliminary optical classification of lakes and coastal waters was proposed by Reinart et al. (2003). It was developed using analyses of water samples and in situ radiation measurements in Estonian and Finnish small lakes.

Lake Peipsi, situated on the border between Estonia and Russia, is the fourth largest lake in Europe by its surface area (3555 km^2) (Nõges, 2001), and therefore needs regular and careful monitoring. Remote sensing could be a powerful tool for this purpose; however, the standard ocean colour products often fail over optically complex waters (Darecki & Stramski, 2004). For making use of valuable satellite information, we first need to develop suitable algorithms based on model simulations or field data.

In the present paper, our goal is to classify L. Peipsi water by its optical properties and study the variation of water types over seasons and locations in the lake. Such information could be used as a foundation for the further development of remote sensing algorithms.

MATERIAL AND METHODS

Description of study sites in Lake Peipsi

Lake Peipsi is a shallow (mean depth 7 m) but large (surface area 3555 km^2) lake on the border of the European Union (Estonia/Russia). It consists of three parts (Fig. 1): L. Peipsi *sensu stricto* (L. Peipsi *s.s.*), L. Lämmijärv, and L. Pihkva. The nutrient load by the Estonian Suur-Emajõgi River (river mouth in south-east L. Peipsi *s.s.*) and the Russian Velikaya River (river mouth in southern L. Pihkva) has caused strong eutrophication of the lake. About 240 inflows enter L. Peipsi and there is only one outflow, the Narva River (north-west in L. Peipsi *s.s.*) carrying water from L. Peipsi to the Gulf of Finland. By analyses in Pihu & Haberman (2001), the average values of biomass indicate moderate eutrophy of L. Peipsi (variation 2–34 g m^{-3}); L. Lämmijärv and L. Pihkva (variation 1–125 g m^{-3}) can be considered eutrophic waterbodies.

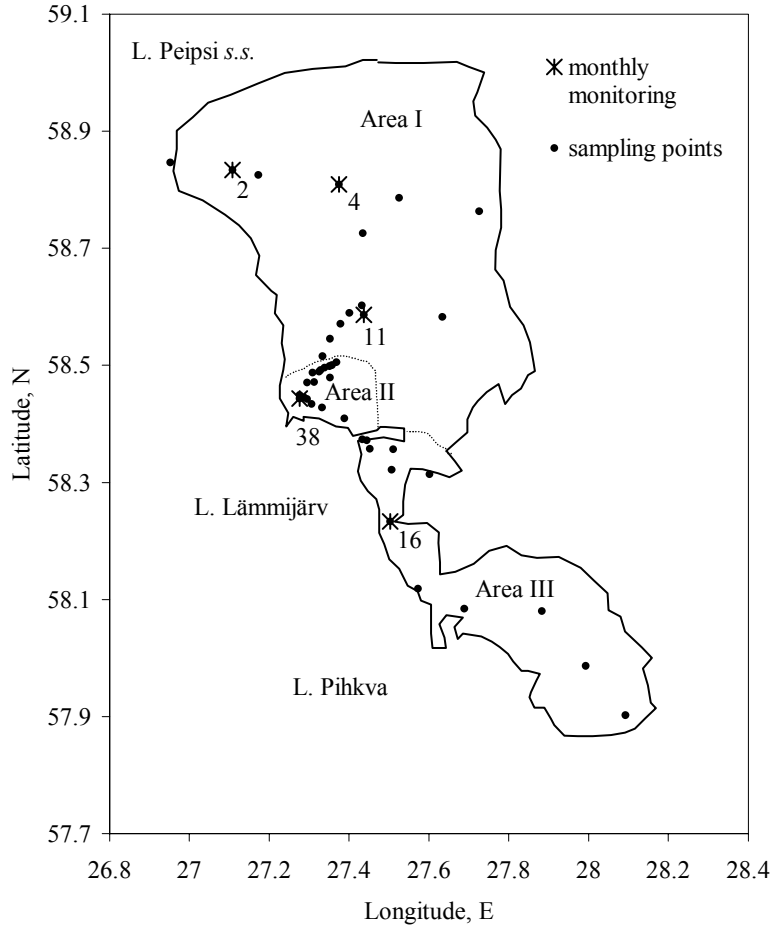

Fig. 1. Location of the sampling points and regular monitoring points in L. Peipsi (numbers are in accordance with the state monitoring programme) and the areas distinguished on the basis of optical characteristics of water.

Access to L. Pihkva is restricted by border regulations and only a small amount of optical data is available for this part of the lake. Regarding biomass and dominant species, the southern part of L. Peipsi *s.s.* close to L. Lämmijärv has always been richer in phytoplankton compared with its middle and northern parts. Scantiness of phytoplankton in the north-western part is evidently related to insufficiency of nutrients.

The present study is a continuation of work on the optical properties of L. Peipsi, published earlier by Reinart et al. (2003, 2004). Therefore, the same data handling and procedures were followed and only a short overview of them is given in the paper. As to its optical properties, L. Peipsi differs from other large European lakes, such as lakes Vänern and Vättern in Sweden (Reinart et al., 2004). There is also great variability of optical properties between different parts of L. Peipsi (Table 1).

Table 1. Characteristics of OAS (mean and standard deviation of concentrations), Secchi depth, and the number of measurements of OAS and reflectance *R* for the study period of 2003–2005

	C_{TSS}, g m^{-3}	C_{Chl}, mg m^{-3}	$a_{CDOM}(442)$, m^{-1}	z_{Secchi}, m	No. of measurements	
					OAS	*R*
Area I	4.5±2.3	12.8±8.3	2.1±0.8	2.0±0.4	61	13
Area II	6.6±4.1	13.9±9.8	2.7±0.9	1.6±0.6	38	18
Area III	17.3±9.5	41.4±33.1	3.4±0.6	0.9±0.3	21	19
L. Peipsi	7.4±6.7	19.1±18.1	2.3±1.2	1.6±0.7	120	50

On the basis of optical characteristics, three different areas can be distinguished in L. Peipsi (Fig. 1). *Area I* covers most of L. Peipsi *s.s.* and the outflow of the lake by the Narva River; this is the deepest (mean depth 7.1 m) and clearest region. *Area II* is located around the inflow of the Suur-Emajõgi River, which brings a large amount of CDOM into the lake. *Area III* includes L. Lämmijärv, which is the narrowest and shallowest part of L. Peipsi (mean depth 2.3 m), and L. Pihkva, whose water is very rich in nutrients (Nõges, 2001).

In 2003, 2004, and 2005, Secchi depth (z_{Secchi}) was measured and water samples were collected regularly from May until the end of August at the sampling points, which were visited during regular state monitoring cruises (numbered as 2, 4, 11, 16, and 38 in www.seiremonitor.ee) and also at some additional locations over the entire lake (Fig. 1). As a result, our database contains 120 samples, which are unequally distributed over different parts of the lake (Fig. 1).

Laboratory analyses of water samples

Water samples were collected from the surface layer (0.2 m) and stored in a dark and cold storage before filtering and analysing by methods suggested by Lindell et al. (1999). The water samples were analysed for the following parameters:

- Chlorophyll *a* concentration (with phaeophytin), designated as C_{Chl}. Water (0.4–1.0 L) was filtered through Whatman GF/F filters; pigments were extracted with 90% ethanol and later analysed by the international standard method (ISO 10260, 1992 (E)).
- Total suspended sediments concentration, C_{TSS}, was measured gravimetrically after filtering 0.4–1.0 L of water through the pre-weighed and pre-combusted Whatman GF/F filters. Filters were dried at the temperature of 103–105 °C for 1 h (Lindell et al., 1999).
- Absorption by coloured dissolved organic matter, a_{CDOM}, was measured with a spectrophotometer Hitachi U-3010 (in the range 280–800 nm) against distilled water. For this, the lake water was filtered through a Millipore 0.2 µm filter. Beam attenuation coefficient was measured with the same instrument. According to Arst (2003), the average value in the region of 400–700 nm, c^*_{PAR}, is a good indicator of water transparency.

Radiometric measurements

The system for measurements of remote sensing reflectance consists of two TriOS-RAMSES hyperspectral radiometers (range 350–950 nm), one facing downwards and the other upwards. RAMSES 817A measures the downwelling irradiance E_d just above the water surface, and RAMSES 8166 measures the upwelling radiance L_w just below the water surface. Spectral diffuse reflectance R was calculated as:

$$R(\lambda) = \frac{L_w(\lambda)}{E_d(\lambda)}.$$

A total of 50 reflectance spectra were collected during 2003–2005 over L. Peipsi *s.s.* and L. Lämmijärv, but none was measured in L. Pihkva (details in Table 1). As the diameter of these sensors is small (4 cm) there is no need for additional shadow corrections (Aas & Korsbø, 1997). Measurements were made during calm and clear days; the solar zenith angle varied between 36° and 45°.

Optical classification of water

Following the statistical method described in Reinart et al. (2003), it is possible to classify lake water, based on the OAS concentrations, into five optical types: *Clear* (C), *Moderate* (M), *Turbid* (T), *Very turbid* (V), and *Brown* (B). The classification scheme is presented in the Appendix. We applied this scheme to all 120 sampling points. The results are analysed below to describe the spatial and seasonal variation of the water type over the lake.

RESULTS

Optically active substances

Concentrations of OAS in the water and z_{Secchi} in L. Peipsi (Table 1) showed a large variation. As it was expected, in *area III*, the water was less transparent and much more turbid than in the other parts of the lake. The water in *area I* was slightly clearer than in *area II*.

To offer a detailed example, we chose the data measured at two points. *Area I* point 2 should represent relatively clear water, which is least affected by the river inflow. *Area II* point 38 (Fig. 1) is located just at the river mouth where the water should contain large amounts of CDOM.

All OAS had generally higher concentrations at sampling point 38 than at the open-water point 2 (Fig. 2). The lowest value of C_{Chl} was registered in June, after quite high values had been recorded in spring. In July C_{Chl} at point 2 started increasing again and the increase continued until mid-August, when C_{Chl} reached the same level as at the beginning of May (about 30 mg m^{-3}). The values of C_{Chl}

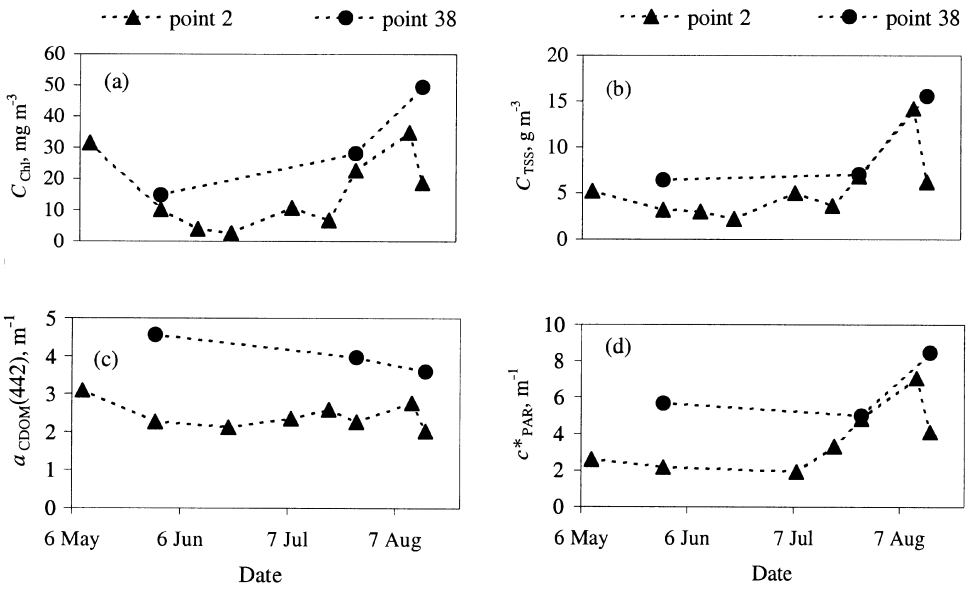

Fig. 2. Temporal variation of water quality parameters at two sampling points of L. Peipsi: (a) concentration of chlorophyll *a*; (b) concentration of total suspended sediments; (c) absorption by dissolved organic matter; (d) beam attenuation coefficient.

in the southern part of L. Peipsi, including point 38 (*area II*), started to increase earlier than in the open region of the lake (*area I*), and rose up to 50 mg m^{-3} (Fig. 2a). In *area III* the C_{Chl} values were even higher (up to 80 mg m^{-3}) and during calm weather conditions, cyanobacterial cells formed visible scum on the water surface.

The temporal course of C_{TSS} was quite similar to that of C_{Chl} (Fig. 2b). However, the C_{TSS} increase in July started later than that of C_{Chl}, but proceeded later quite sharply. This kind of delay was stronger at locations close to the shore or at river mouths than over the open expanse of the lake. The amount of CDOM was much higher at the river mouth (point 38) than in the open lake (point 2) (Fig. 2c).

The variability in OAS is directly related to the variation in the optical properties of water. In Fig. 2d, it can be seen that the PAR attenuation coefficient c^*_{PAR} was higher in early spring and summer, when the amount of CDOM was also higher (Fig. 2c) over the entire lake; later in summer, a c^*_{PAR} increase followed an increase in C_{Chl} (Fig. 2a). As a result, in spring c^*_{PAR} was about three times as high at point 38 as at point 2, but in August they were almost equal.

Seasonal and temporal variation of the optical type of water

Concentrations of OAS were used to classify all samples into optical water types. The majority of the points (65%) belonged to *Moderate* type, 16% to

Turbid, and 9% to *Clear* type; only 5% were classified as *Very turbid* and 5% as *Brown* types. To show seasonal variations, the whole dataset of 2003–2005 (120 samples) was divided into 2 periods: May–June and July–August. Twelve measurements were made in May; 75% of the samples belonged to *Moderate* and 25% to *Brown* types. Water samples taken in July also mainly belonged to *Moderate* (84%) and *Turbid* (12%) types; a small part of them (4%) fitted into *Very turbid* type. In August, 64% of 22 measurements belonged to *Moderate* type, 18% were classified as *Turbid* and 18% as *Very turbid*.

The spatial variation of the optical properties of water in L. Peipsi was different in spring and summer periods (Fig. 3). A total of 61 sampling points were located in *area I*; 81% of them belonged to *Moderate* type, which dominated in both spring and summer. *Clear* type was found also in both periods, but typically in May and June (11%). Only 2% of all cases belonged to *Turbid* type of water and *Very turbid* type was not present in *area I*.

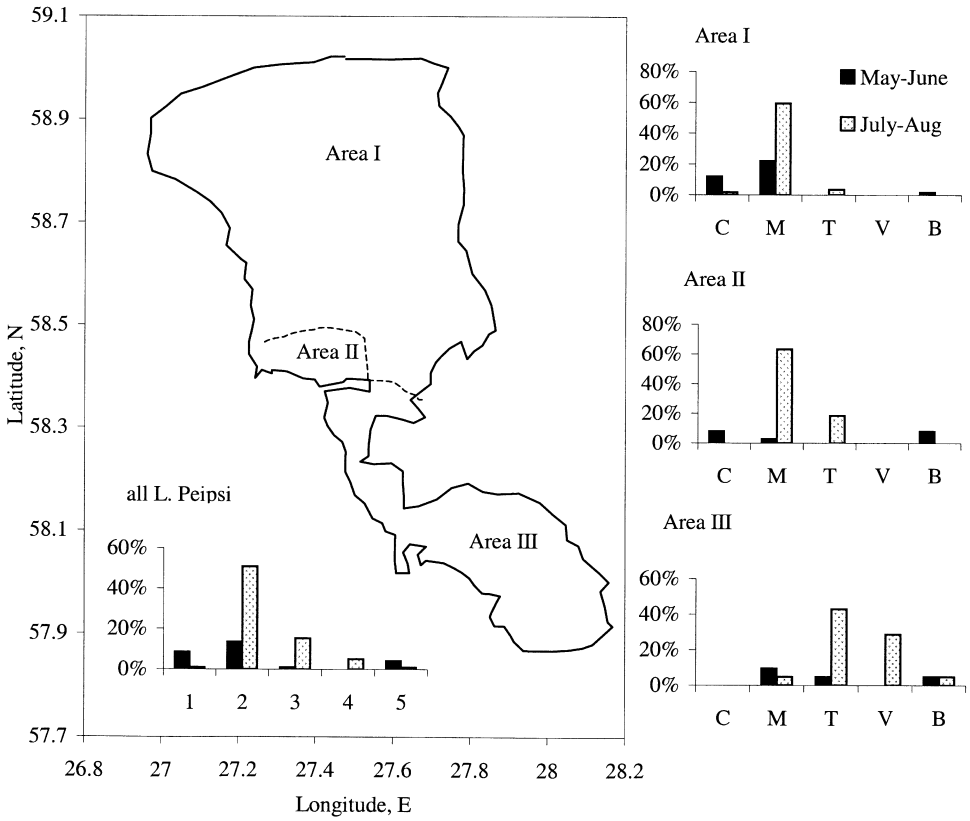

Fig. 3. Variation in optical types of water in L. Peipsi according to the measured optically active substances in 2003–2005. Water types: C – *Clear*, M – *Moderate*, T – *Turbid*, V – *Very turbid*, B – *Brown*.

Very turbid type was not present in *area II* either. Similarly to *area I*, *Moderate* type was most common in *area II* as well (66%); *Brown* type could be found in May and June (8%), and so could *Clear* type, which was located off the river mouth. In July and August, the water belonged to *Turbid* type in more cases than in *area I* in August.

Area III differs from the others, as at 21 sampling points *Clear* type was not represented at all and only 15% of the cases belonged to *Moderate* type. Instead, *Turbid* type (48%) was most common even in May and June, and later in summer the water turned into *Very turbid* type; *Brown* type could also be detected from early spring throughout the summer.

Attenuation spectra

Average beam attenuation coefficients according to each water type are shown in Fig. 4. They express differences in the amount of OAS. *Turbid* and *Very turbid* types have the highest attenuation at wavelengths longer than ~450 nm because of high scattering by particles. The attenuation of *Brown* type is especially high at shorter bands (>450 nm) due to the absorption by CDOM. *Clear* and *Moderate* types have the lowest attenuation because of the lower concentrations of each OAS.

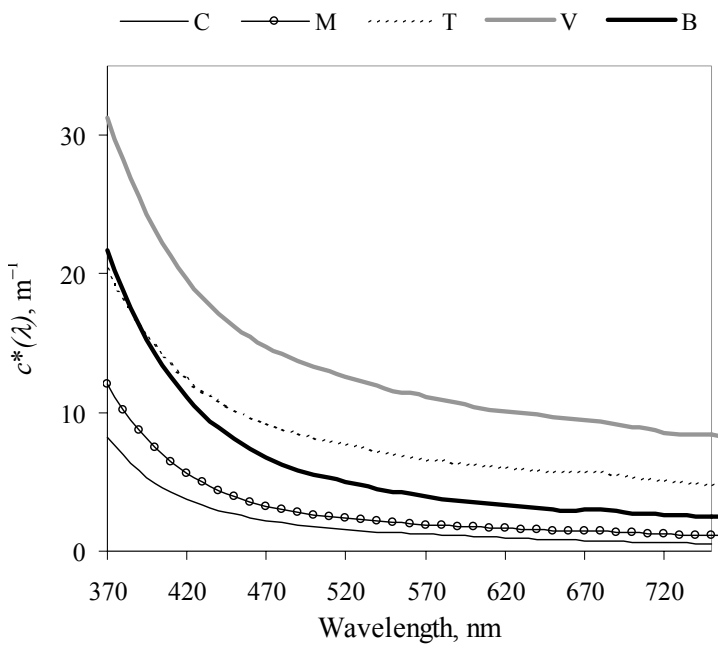

Fig. 4. Spectral beam attenuation coefficient measured in optically different types of water. Water types as in Fig. 3.

Reflectance spectra

The reflectance spectra measured in L. Peipsi showed very low values below 450 nm, which is caused by a rather high content of CDOM. To describe the spectral variation of each water type, we normalized the reflectance spectra to the wavelength of 590 nm. Examples characterizing each water type are presented in Fig. 5. Three types – *Clear*, *Very turbid*, and *Brown* (Fig. 5a) – could easily be distinguished from one another. The spectra according to *Clear* water type had a strong maximal reflectance in the region of 565–575 nm, which decreased with increasing wavelength. In the case of *Very turbid* water type, very strong absorption occurred around 440 nm and additional absorption features were notable around 610–630 and 680 nm. Therefore, in the normalized reflectance spectra, three peaks could be recognized, among which the first one coincides with the *Clear* maximum, but the strongest one was located in the region of 690–730 nm. *Brown* water spectra differed from other types showing the smoothest spectral variance in the region of 590–700 nm, even the same peaks were notable. Because of the strongest absorption by CDOM, the location of the first maximum is shifted towards longer wavelengths (590 nm).

The spectra of *Moderate* and *Turbid* water types were very similar in the blue region of the spectrum, their difference increased above 500 nm. They differed from *Clear* type (Fig. 5b) in having a lower first maximum (effect of larger absorption by CDOM) and higher reflectance above 500 nm (caused by a large amount of suspended particles).

Variability of OAS over seasons and regions of the lake caused variability also in the reflectance spectra used in remote sensing applications. We will take a closer look at the MODIS sensor, as these images are freely available for each clear day. To clarify how well the MODIS sensor could discriminate between the estimated water types, all measured spectra were re-sampled according to the MODIS bands. The average and standard deviations at some of the most characteristic bands are listed in Table 2 for each water type.

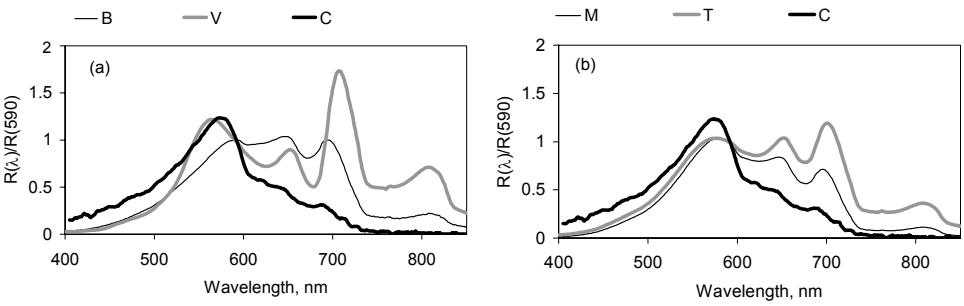

Fig. 5. Spectra of remote sensing reflectance normalized at 590 nm characterizing each water type determined in L. Peipsi. Water types as in Fig. 3.

Table 2. Average and standard deviation of $R(\lambda)/R(590)$ calculated from measurements in L. Peipsi according to each water type. Measured spectra were re-sampled according to the selected MODIS bands

MODIS band	Water type				
	Clear	*Moderate*	*Turbid*	*Very turbid*	*Brown*
B10: 490 nm	0.41±0.02	0.31±0.04	0.28±0.03	0.23±0.01	0.35±0.06
B11: 531 nm	0.78±0.01	0.56±0.04	0.66±0.03	0.67±0.01	0.61±0.04
B12: 553 nm	**0.99±0.02**	**0.86±0.03**	**0.90±0.03**	**1.00±0.07**	0.77±0.03
B2: 659 nm	0.56±0.06	0.80±0.03	0.86±0.03	0.81±0.03	**0.99±0.01**
B14: 681 nm	0.41±0.05	0.64±0.04	0.69±0.04	0.58±0.04	0.087±0.02
B15: 750 nm	0.059±0.03	0.14±0.03	0.24±0.04	0.44±0.04	0.26±0.05

Bold numbers show the location on the maximum in reflectance spectra for each water type.

DISCUSSION

Lake Peipsi differs from other large European lakes (Vänern and Vättern), the water of which belongs mainly to *Clear* type (Reinart et al., 2004). The water of L. Peipsi is mostly classified as *Moderate* type, indicating that it is a mixture of different substances. Therefore it could be assumed that remote sensing algorithms developed for clear lakes or seas cannot be used for such an optically complex waterbody and there is a need for specific algorithms.

Hydrological and biological cycles in the lake cause the variation of OAS to such an extent that optical properties, such as attenuation and reflectance coefficients, also vary seasonally and spatially over the lake. Due to the melting of snow and a high groundwater level, the river runoff is higher in spring (Nõges, 2001) and therefore, $a_{\mathrm{CDOM}}(442)$ over the entire lake is also higher in spring. Phytoplankton bloom is largest in late summer (and autumn) (Pihu & Haberman, 2001) and causes high reflectance then.

Unfortunately, reflectance measurements were not performed each time when water samples were taken. Nevertheless, the representation over water types is almost the same as it was shown above: of the 50 spectra, most (64%) were measured in *Moderate*, 20% in *Turbid*, 8% in *Clear*, and 4% in both *Very turbid* and *Brown* types of water. The spectra measured in L. Peipsi characterizing *Brown* type of water actually do not fit into the spectra reported for *Brown* water type, but represent the mixed type *Moderate*/*Brown* also described by Reinart et al. (2003). The reason may be that the original classification was developed for small lakes and the database did not include a representative amount of *Brown* lakes. *Moderate* type was the most common for all periods. In May, *Brown* type of water was measured in all three areas listed in Table 1, at the points closest to the river mouth and the shore.

MODIS has no bands in the ranges of 551–620 nm and 690–750 nm, therefore, not all peaks in the spectra that can be seen in Fig. 5 can be recognized in the MODIS spectra. Also, the band centred at 659 nm is rather wide (50 nm) and therefore the effects at 630 and 659 nm (characteristic of cyanobacteria) may compensate for each other. It was already shown by the examples in Fig. 5 that *Clear* type can be distinguished from other types by a higher normalized reflectance at bands 490 and 531 nm and a significantly lower reflectance at longer bands. The reflectance maximum is located in the band of 551 nm for all water types, except *Brown* type, where it has shifted into the red band (659 nm). This band is, however, an uncommon ocean colour band, and therefore it is not included into the standard processing scheme. Difference between *Turbid* and *Very turbid* types is notable only in the band of 681 nm, which was specially designed for the studies of chlorophyll concentration. This also fits into the classification scheme (Reinart et al., 2003), where a change in water type was actually caused by an increasing phytoplankton bloom in some lakes. It is not possible to discriminate between *Moderate* and *Turbid* water types by means of standard MODIS processing, as the difference between these types is significant only in the 750 nm band, which is used but as a reference for the atmospheric correction procedure. High reflectance values in this band (25–44% of maximal reflectance) will certainly cause errors in atmospheric correction over these waters, as has often been observed before (Carlund et al., 2005).

For remote sensing applications, it is really crucial to identify more precisely *Moderate* and *Turbid* water types in L. Peipsi by the means of OAS as well as by optical properties. These are the most typical features, but at the same time the hardest to detect by the most common ocean colour sensor MODIS. Class *Brown* is sampled only occasionally at the sampling points close to the river mouth and in narrow L. Lämmijärv. These points are probably always masked out on the satellite images, whose pixel size varies between 300 m and 1 km.

CONCLUSIONS

A three-year intensive study of the OAS and reflectance of L. Peipsi showed the variation of optical water types in L. Peipsi both seasonally and spatially. The most common water type was *Moderate* (65%); 16% of the water belonged to *Turbid* type and 9% to *Clear* type; only 5% of the samples were classified as *Very turbid* and also 5% as *Brown*.

Variation among water types was most pronounced in May, when the largest area of L. Peipsi belonged to *Moderate* and *Clear* types; L. Lämmijärv and L. Pihkva often represented *Turbid* type of water. *Brown* type could be found at the river inflow and near the shore. During summer, L. Peipsi *s.s.* water was of *Moderate* type and L. Lämmijärv and L. Pihkva were of *Turbid* and *Very turbid* types.

Each water type has characteristic reflectance spectra, which can be used for a remote sensing algorithm for water quality estimations. Despite the differences in the OAS, the reflectance spectra in *Moderate* and *Turbid* types cannot be distinguished by the standard processing scheme of the MODIS sensor because of its lack of suitable bands. *Clear* and *Very turbid* types can be recognized using the MODIS bands. *Brown* type can be found only at the points closest to the shore and therefore it is not relevant for ocean colour satellite applications.

For further remote sensing applications in L. Peipsi, *Moderate* and *Turbid* types need to be better defined, since they are most commonly found, but so far, poorly described. The shapes of the reflectance spectra of these types differ only at the wavelengths longer than 600 nm.

ACKNOWLEDGEMENTS

This study was supported by the EU Marie Curie Reintegration Grant MERG-2004-004401 and the Estonian Science Foundation grants 6814 and 5738. We appreciate the help rendered by the Estonian Maritime Administration by providing a boat for the field survey, and express our gratitude to the team of the Tiirikoja station of the Estonian Meteorological and Hydrological Institute for their help in field sampling and to E. Lill from the Võrstjärv Limnological Centre for the analyses of water samples.

APPENDIX

SCHEME OF OPTICAL CLASSIFICATION OF WATER

Optical classification of Estonian and Finnish lakes, applicable also for coastal waters of the Baltic Sea, was made by the K-means clustering technique (details are given in Reinart et al. (2003)). It was assumed that these waters can be divided into five optically different classes: C (*Clear*), M (*Moderate*), T (*Turbid*), V (*Very turbid*), and B (*Brown*). Input parameters are C_{chl}, C_{TSS}, and $a_{\mathrm{CDOM}}(380)$. To determine to which class (C, M, T, V, or B) a water body is most likely to belong, the classification scores S_i need to be computed:

$$S_i = c_i + w_{i1}x_1 + w_{i2}x_2 + w_{i3}x_3, \tag{A1}$$

where i denotes the class C, M, T, V, or B; values $w_{i1,2,3}$ and c_i are the parameters when computing S_i for each class (values in Table A1); $x_{1,2,3}$ are the observed values of the variables. Each case is classified as belonging to the class in which it has the highest classification score. When the amount of OAS was used as input, the percentage of correct classification was 100.

Table A1. Parameters for the calculation of classification scores for lake optical classification

Parameter	Water type				
	Clear	*Moderate*	*Turbid*	*Very turbid*	*Brown*
C_S	0.61	1.73	3.73	7.73	3.02
C_{chl}	0.18	0.50	1.06	1.78	0.79
$a_{CDOM}(380)$	0.97	3.04	4.50	6.89	5.85
Constant c_i	−3.09	−20.64	−64.70	−217.55	−70.04

These classes can be briefly described as follows. In C type, the amount of OAS is the smallest among these types and the water is the most transparent (mean z_{Secchi} = 4.4 m). In M type, the water is darkened due to increased CDOM (mean $a_{CDOM}(442)$ = 2.5 m^{-1}) and also more turbid because of a higher amount of suspended sediments (mean C_{TSS} = 3.8 g m^{-3}). In T and V types, phytoplankton bloom (mean C_{chl} is 30.5 and 66.4 mg m^{-3}, respectively) may cause high scattering, and CDOM is slightly lower than in M type. In B type, the amount of CDOM is very high (up to $a_{CDOM}(442)$ = 8 m^{-1}) while other parameters are comparable with type M.

REFERENCES

Aas, E. & Korsbø, B. 1997. Self-shading effect by radiance meters on upward radiance observed in coastal waters. *Limnol. Oceanogr.*, **42**, 968–974.

Arst, H. 2003. *Optical Properties and Remote Sensing of Multicomponental Water Bodies*. Springer, Praxis Publishing, Chichester, UK.

Carlund, T., Håkansson, B. & Land, P. 2005. Aerosol optical depth over the Baltic derived from AERONET and SeaWiFS measurements. *Int. J. Remote Sens.*, **26**, 233–245.

Darecki, M. & Stramski, D. 2004. An evaluation of MODIS and SeaWiFS bio-optical algorithms in the Baltic Sea. *Remote Sens. Environ.*, **89**, 326–350.

ISO 10260, 1992 (E). *Water Quality – Measurement of Biochemical Parameters – Spectrophotometric Determination of Chlorophyll Concentration*. Geneva, Switzerland, ISO, 1–6.

Lindell, T., Pierson, D., Premazzi, G. & Zilioli, E. 1999. *Manual for Monitoring European Lakes Using Remote Sensing Techniques*. Office for Official Publications of the European Communities, Luxembourg.

Martin Traykovski, L. V. & Sosik, H. M. 1998. Optical classification of water types based on remotely-sensed ocean colour. In *Ocean Optics XIV Conference Proceedings (10–13 November 1998, Kailua-Kona, HI)*. CD-ROM.

Mobley, C. D. 1994. *Light in Water-Radiative Transfer in Natural Waters*. Academic Press, San Diego.

Morel, A. & Prieur, L. 1977. Analysis of variations in ocean color. *Limnol. Oceanogr.*, **22**(4), 709–722.

Nõges, T. (ed.) 2001. *Lake Peipsi. Meteorology, Hydrology, Hydrochemistry*. Sulemees, Tartu.

Pihu, E. & Haberman, J. (eds) 2001. *Lake Peipsi. Flora and Fauna*. Sulemees, Tartu.

Reinart, A., Herlevi, A., Arst, H. & Sipelgas, L. 2003. Preliminary optical classification of lakes and coastal waters in Estonia and South-Finland. *J. Sea Res.*, **49**, 357–366.

Reinart, A., Paavel, B. & Tuvike, L. 2004. Effect of coloured dissolved organic matter on the attenuation of photosynthetically active radiation in Lake Peipsi. *Proc. Estonian Acad. Sci. Biol. Ecol.*, **53**, 88–105.

Optiliste veetüüpide varieeruvus Peipsi järves

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Peipsi järv on pindalalt suur (3555 km^2), magedaveeline ning madal ja vajab seepärast regulaarset ning hoolikat jälgimist. Kaugseire võiks olla selleks väga hea vahend, aga ookeanivete jaoks välja töötatud standardsed meetodid ei sobi optiliselt keerukate vete – nagu järved ja rannikuveed – korral. Peipsi järves on kolme aasta jooksul läbi viidud hulgaliselt välitöid optiliselt aktiivsete ainete ja peegeldusteguri määramiseks. Nendest andmetest võib järeldada, et Peipsi järve vesi kuulub üldiselt Mõõdukasse (65%) optilisse veetüüpi, 16% Sogasesse, 9% Selgesse, 5% Väga sogasesse ja 5% Pruuni veetüüpi. Veetüübid järves on muutlikud nii ajas kui ka ruumis ja seepärast on vajalik välja töötada veetüüpide klassifikatsioon, mida saaks satelliidipiltide korral automaatselt rakendada. Artiklis on näidatud, et MODIS-e sensori tulemustest on võimalik ära tunda Selget ja Väga sogast veetüüpi. Optiliselt aktiivsete ainete kontsentratsioonide erinevusest hoolimata ei ole Mõõduka ja Sogase veetüübi peegeldumisspektrid MODIS-e sensori standardse töötluse tulemuste alusel eristatavad. Kasutamaks satelliitkaugseiret Peipsi järve monitooringuks, oleks vaja täpsemaid Mõõduka ja Sogase veetüübi definitsioone.