A Bayesian network for evaluation of setting and reaching the targets of the Water Framework Directive

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Summary
This work describes the development of the EU Water Framework Directive central water quality elements from 1970 to 2010 in the Gulf of Finland, a eutrophied sub-basin of the Baltic Sea. The likelihood of accomplishing the management objectives simultaneously is assessed using Bayesian networks. The objectives of good ecological status in summer-time nutrient concentration, chlorophyll *a* concentration and Secchi depth are not met at present and it is unlikely for them to be achieved in the near future, despite the decreasing trend in nutrient concentrations last years. It was demonstrated that neither phosphorus nor nitrogen alone controls summer-time plankton growth. Reaching good ecological status in nutrients does not necessarily lead to good ecological status of chlorophyll-a, even though a dependency between the parameters does exist. In addition, Secchi depth status is strongly related to chlorophyll-a status in three of the four study-areas.

Introduction
The Water Framework Directive (WFD) is currently the most important legislative framework in the management of water quality in inland and coastal waters of the EU. The aim is to reach good ecological status in all waters by 2015 which is determined by assessment against defined reference level. Ecological status is divided into five classes or levels (high, good, moderate, poor and bad). The targeted status to be achieved being at least the boundary between good and moderate status. No absolute standards for the good status can be given across all European waters (EC, 2000), but a guidelines for the definition of the reference condition is implemented by each Member state. Good ecological status is achieved when biological communities present are close to those that present with minimal anthropogenic disturbance. Not a trivial task due to lack of data or areas having specific properties. E.g., Baltic Sea is a shallow, semi-enclosed brackish-water area characterized by a slow water renewal and a 4 times larger drainage basin in relation to its surface water area. Eutrophication in the Baltic Sea resulting from the long human exploitation of natural resources has been identified as key pressures. In Finnish coastal waters, ecological classification has been based on summertime chlorophyll *a* concentration (chl-*a*), Secchi depth, total nitrogen (tot-N) and phosphorus (tot-P) concentration. In this work, the ecological status and the trends of summertime chl-*a* and Secchi depth are examined (1970-2010) in the Gulf of Finland. This was done previously in relation to wintertime tot-N and tot-P (Fernandes et al., 2012). Here, we update that work using the latest updates in the WFD which consider now summertime nutrients, new reference values and new quality boundaries.

Material and Methods
Using the high/good and good/moderate boundary values defined by the water directive as targets (Table I), the achievement of high and good ecological status in coastal areas of the Gulf of Finland is studied. Finally, using probabilistic models, synchrony of the target levels set for each variable is examined in the Gulf of Finland, i.e. the likelihood of reaching the target values of chl-a when the target values of nutrients are met. In particular, the uncertainties of the relationships between levels of nutrients and the other variables levels are evaluated. This uncertainty is crucial in predicting the development toward good ecological status in chl-a and Secchi depth by managing nutrient amounts in river basins by the WFD implementation actions. Probabilistic models have been used to deal with uncertainty, provide an intuitive interface to data and produce forecasts (Fernandes et al., 2010, 2013).

Results and Discussion

The coastal Gulf of Finland is far from reaching good ecological status by 2015. Based on the current target values set for chl-*a* outer coastal waters were close to good status in the late 1970s and early 1980s, though the area was reported to suffer from eutrophication (Pitkänen et al., 1987). The probability to achieve a desired impact in chl-*a* given the decreased nutrient level or the targeted Good/Moderate was low (Table I). Neither phosphorus nor nitrogen alone controls summer-time plankton growth, which was demonstrated by neither nutrient being more consistently in good status when good chl-*a* status was met. Nevertheless, the fact that the probability of good summer-time chl-*a* status increased with increasing winter-time nutrient status in the Western and Eastern inner coastal areas, indicates a dependency between the metrics. The weakness of this dependency can be interpreted as an unharmonised target-setting (Borja et al., 2011). The probabilistic methodology employed is a flexible tool for examining data (Uusitalo et al., 2007) or modelling processes (Andonegi et al., 2011). In this work, the tool was used simply for creating an easy-to-understand interface for exploring the relationships of the variables in the data and the rules the directive will use. No other information, such as Bayesian priors was used. Therefore, the model simply serves as a tool which provides an accessible interpretation of the data following the procedures being taken in the WFD.

Coasta l area →		Western inner			Western outer			Eastern inner			Eastern outer		
Vars.	Levels	Basic State	Nutr. *Good*	Chl-*a* *Good*	Basic State	Nutr. *Good*	Chl-*a* *Good*	Basic State	Nutr. *Good*	Chl-*a* *Good*	Basic State	Nutr. *Good*	Chl-*a* *Good*
Tot-N	*High/Good*	0.15	*1.0*	0.20	0.09	*1.0*	0.11	0.07	*1.0*	0.13	0.11	*1.0*	0.40
	Mod.	0.60	*0.0*	0.70	0.61	*0.0*	0.76	0.32	*0.0*	0.38	0.49	*0.0*	0.42
	Poor/Bad	0.25	*0.0*	0.10	0.30	*0.0*	0.13	0.61	*0.0*	0.49	0.40	*0.0*	0.18
Tot-P	*High/Good*	0.21	*1.0*	0.10	0.14	*1.0*	0.70	0.13	*1.0*	0.31	0.25	*1.0*	0.53
	Mod.	0.56	*0.0*	0.70	0.58	*0.0*	0.29	0.29	*0.0*	0.30	0.36	*0.0*	0.25
	Poor/Bad	0.23	*0.0*	0.20	0.28	*0.0*	0.01	0.58	*0.0*	0.39	0.39	*0.0*	0.22
Chl-*a*	*High/Good*	0.01	0.18	*1.0*	0.10	0.01	*1.0*	0.06	0.12	*1.0*	0.13	0.53	*1.0*
	Mod.	0.51	0.80	*0.0*	0.61	0.98	*0.0*	0.30	0.48	*0.0*	0.49	0.42	*0.0*
	Poor/Bad	0.48	0.02	*0.0*	0.29	0.01	*0.0*	0.64	0.40	*0.0*	0.38	0.05	*0.0*
Secchi	*High/Good*	0.06	0.06	0.94	0.03	0.04	0.01	0.05	0.07	0.23	0.09	0.20	0.32
	Mod.	0.89	0.90	0.03	0.47	0.59	0.88	0.24	0.32	0.41	0.41	0.49	0.47
	Poor/Bad	0.05	0.04	0.03	0.50	0.37	0.11	0.71	0.61	0.36	0.50	0.31	0.21

Table I. Probabilistic scenarios in each area for summertime chlorophyll *a* (Chl-*a*), Secchi depth, total nitrogen (Tot-N) and phosphorus (Tot-P) concentration. Firstly, the posterior probability distribution of the annual water body averages based on data frequencies is show. Secondly, the posterior distribution is presented under the scenario of both nutrients at *good* or *high* state. Finally, posterior distribution under the scenario of chl-*a* is at *good* or *high* state.

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