ALGAE AND HYDROPOWER. ATTACHED ALGAL VEGETATION AS INDICATOR OF DISTURBANCES OF THE LOTIC ECOSYSTEM

ALGER OCH VATTENKRAFT. FASTSITTANDE ALGER SOM INDIKATORER PÅ STÖRNINGAR I STRÖMMANDE VATTEN

Catarina Johansson, cattis48@gmail.com
FD i växtbiologi, Växtbiologiska institutionen, Uppsala

Abstract
The aim of this article is to present an approach (modus operandi) for producing recommendations regarding potential hydropower development. A study of attached algae in 27 streams in mid Sweden according to extension of hydropower or not was carried out. The samples were taken already in 1982 and some of the streams and parts of rivers have been protected since then and are not subject to development. On the other hand, some of the unregulated sites have been developed for hydropower. Species of attached algae (periphyton, benthic algae) were used as indicators and together with the approach of clustering and polar ordination for showing connections or disconnection between sites it resulted in four classes according to degree of action (protection or extension). The theory of island biogeography has been used as one of the main reasons for not developing more hydropower. The main contribution is to point out the importance of saving most rapids not affected by regulation since most large and middle-sized rivers in our country (and the rest of the world) are developed for hydropower and consequently the normal torrential flora (and fauna) is very vulnerable.

Sammanfattning
Syftet med denna artikel är att presentera ett tillvägagångssätt (modus operandi) för att tillhandahålla rekommendationer när det gäller vattenkraftutbyggnad. En studie av fastsittande alger (perifyton, bentiska alger) har utförts i 27 vattendrag i mellersta Sverige (Jämtland). Proverna togs redan 1982 och några av vattendragen har därefter blivit skyddade mot vattenkraftsutbyggnad och några har exploaterats för samma ändamål. Arter av de fastsittande algerna användes som indikatorer och tillsammans med kluster analys och polär ordination, som visade de olika lokalernas samhörighet, resulterade denna studie i en indelning av fyra klasser beroende på grad av åtgärd (bevarande eller utbyggnad). Öbiogeografiska teorin har applicerats för att motivera att de oreglerade strömmar som finns kvar skall bibehållas. Det huvudsakliga bidraget är att påpeka vikten av att bevara de strömmar som fortfarande hyser en för rinnande vatten normal flora (och fauna) då de flesta stora och medelstora vattendrag i vårt land (och resten av världen) är utbyggda för vattenkraft varvid en normal rinnande vattenflora (och fauna) är mycket sårbar.

Key words: hydropower, Sweden, attached algae.

Introduction

The aim of this article is to present an approach (modus operandi) for producing recommendations regarding potential hydropower development. The basis for the scheme I suggest is the study of attached algal vegetation at a variety of sites, the application of cluster analysis and polar ordination on the data, and finally the application of the theory of island biogeography. Together, and correctly performed, I argue, these approaches make up a sound basis for policy recommendations from a biodiversity point of view, in the case of potential hydropower development.

The study of attached algal vegetation is, as written above, the basis for the scheme of policy recommendations I present in this article. The study consists of an inventory and analysis of the attached algal vegetation (periphyton, benthic algae) in 27 stream sites located in different water courses in near alpine areas in mid Sweden. The study was originally performed precisely in order to predict the effects in case of development of hydropower. The region was thoroughly studied by the author during a 20-year period (1972 - 1992) and good statistical material about surrounding factors and algal species and communities are available (Johansson 1982a, Johansson 1982b).

Water flow governs the fundamental nature of streams and rivers, so it should come to no surprise that the modification of flow caused by dams alters the structure and function of river ecosystems. Attached algae are:

- the main primary producers in fast-flowing streams and react comparatively fast on changed water conditions,
- attached to the substrate and as such they do not escape (like fishes) suddenly from their location,
- easy to collect and nowadays comparatively easy to identify due to photo digitalisation and the international network,
- frequently used as indicators (Damm, van 1994).

Several studies on regulated streams by hydropower and effects on biota have been carried out. Most well known is the impact on migrating fish where the negative influence is enormous since dams effectively cut off the migrating routes. The benthic algal species will change from so called torrential or lotic species - dependent of the oxygen rich water and clean flushed bottoms for their survival - to species adapted for more lenitic (slow-flowing) circumstances.

Attached algal cells or threads can easily move to new attractive substrate either transported by water flow, wind or animals especially birds (between the toes). Compared to animals such as bottom fauna and fish, algae are more capable of colonising new areas as far as the substrate and water flow are suitable. This means that for example rapids left in regulated streams can be appropriate for algal colonisation - the more natural flow the more torrential algal flora. This investigation is supposed to estimate to what extent the algal flora will deviate from the expected when development of hydropower will occur and recommendations of the studied sites suitable for extension or protection. The natural torrential flora and their surrounding parameters elsewhere in northern alpine or near-alpine streams and rivers all over Scandinavia are well described in Johansson (1982a; 1982b).

The theory of island biogeography is one of the most important concepts in ecology and evolution (Mac Arthur & Wilson 2001). It describes how different habitats vary in population number and diversity. The theory of island biogeography is also the most helpful and applied theoretical concept when it comes to policy recommendations. As we know hydropower development and hydropower production disturb ecological functions in rivers and dams hinder natural flows of nutrients, sediment and organisms through landscapes. The basic theory says that on larger islands there is a larger number of species, while smaller islands have less species diversity.

The theory of island biogeography concept does not just involve islands. In the theory, an "island" can be any ecosystem that is different from the ecosystems around it, such as an oasis in the desert or

a small rainforest surrounded by farmland or as in this study remaining rapids in rivers heavily regulated for hydropower. The theory of island biogeography concept has been used in the conservation biology as the development of habitat corridors, thin strips of habitats connecting two similar areas that would otherwise be isolated as islands - such as in this study- rapids between hydropower dams. Therefor it is of great value to establish nature reserves to create ecological islands to keep as high variety as possible of plant- and animal species, usable in the future for restoration work.

The present study focuses on (i) description of the algal flora per sampling site, (ii) expected effects caused by extension of hydropower, (iii) statistics illustrating the similarities or dissimilarities of the sites, and (iv) recommendations.

Methods

Sampling and quantification

The samples were taken in mid August 1982. At that date the algal flora had reached a stable community. Twenty stones were picked out randomly along a stream stretch of about 20 m. The stones were brushed off and the algae were gathered in a bucket from which subsamples were taken. Focus was carried out on dominating algae which means that no extra time was added to search for rare species. The estimation of the algal species cover degree were made directly in the stream - if possible - otherwise in the microscope. A semiquantitative biomass scale, with roughly the following cover percentage degree (100 divided in six equal parts), was given, where 6=83-100%, 5=67-83%, 4=50-67%, 3=33-50%, 2=17-33%, 1=<17% (≠ 0). The cover percentage can exceed 100% since several layers of algae exist. The quantification of biomass was carried out as the sum of biomass entities (1-6) per site. The species found belong to the algal divisions, such as green algae, blue-green algae, red algae and diatoms.

Species identification

The following main floras were used for identification of the algal species: Hustedt (1930), Geitler (1930-1932), Bourrelly (1966), Israelson (1942). The identification of diatoms and also other algae is progressing over time - as with all species identification work. Nowadays new articles on species are available and some of the species in this study have changed names and/ or have been split or compiled into new taxa. When doing a study as basis for policy recommendation it is particularly important to specify floras, as a follow up might be performed by new scientists for continued inventories in the future.

Sites

The 27 chosen sites were based on the possibility for the hydropower industry to gain more energy either by extension of the already built hydropower plants or creating new plants in parts of rivers where still some remaining rapids exist. Four of the sites (6, 8, 10 and 29) were sampled in 1975-76 and just an overview of the algae was given in this study. 6, 8, 10 and 29 were neither included in the cluster analysis nor in the polar ordination. Below the sites are presented according to the main drainage area from north to south - numbers in brackets refer to sites in figures and tables:

- Fjällsjö river - the Ångerman river: the Lejar river (29), the Flåsjö stream (30),
- Indal river: the Handöl stream (1), the Tege rapids (2), the Mattmar stream (3), the Landverk stream (4), the Tänn rapids (6), the Svarthål rapids (18), the Hammar rapids (19), the Gammelänge site (20a), the Krångede site (20b), the Stadsforsen site (22),
- Långan river:the Korsvatten stream (14), the Rönnö rapids (8),the Lång rapids (9),
- Hårkan river: the Tosk stream (10), the Edsox rapids (25), the Hög rapids (26),
- Ammer river: the Storå stream at Lillfulvurn (11), the Storå stream at Lakavattnet (12), the Hökvattnet tributary, (13), the Borgforsen site (21), the Springhällarna site (32),
- Ljusnan river:the Broforsen site (15), the Glissjöberg site (16), the Linsellborren site (17),
- Ljungan river: the Sölvbacka rapids (23).

Results

Algal species composition

Below the sites are presented one by one according to the main river drainage areas and in a north-south orientation:

The Fjällsjö river

The Lejar river (29) is one of the tributaries to the Lake Stora Blåsjön in the very north of Jämtland and is the most northerly located site in this study. The algal flora was dominated by the Zygnemales and diatoms and the whole area is embossed by ultra-oligotrophy because of the surrounding alpine mountains.

The Flåsjöån stream (30) site was located at the outlet of the Lake Flåsjön (regulated for hydropower) just below a small dam construction. The stream was unregulated between the lake and until it 10 km downstream flows into the regulated the Fjällsjö river at the village of Hoting. The site bottom was overgrown with the green alga Bulbochaete sp. corresponding to a biomass 3 together with greyish clouds of the diatoms Tabellaria flocculosa and T. fenestrata - both with biomass 6. Tabellaria fenestrata prefer waters downstream lakes or dams according to Johansson (1982b). The diatoms Eunotia arcus and E. pectinalis - prevalent in waters with lower pH, conductivity and calcium than the reference curve Johansson (op cit). The site was also characterised by fewer species than the mean but with one of the highest total biomass content (Table 1). The species composition was disturbed by the changed water flow due to regulation, lacking so called torrential species dependent of the oxygen rich water and clean flushed bottoms for their survival.

The Indal river

In the Handölan river (1) two hydropower plants exist close to each other in the lower part of the river near the Handöl village.The upper one has a fall of 70 m and the lower one 36 m. The Handölan river is surrounded by the Nature reserve of the Vålådalen. The samples were taken between the two plants, where alpine birch forest with blueberry in the field layer dominated along the stream. The dominating algae were as expected in northern turbulent, clean waters the Zygnemales - here the species Zygnema b was the most apparent. The blue-greens which often colonise the stones in fast flowing waters were here represented by Tolypothrix distorta v. penicillata and Rivularia biasolettiana. The quantitatively most important species were the diatoms Tabellaria flocculosa and Cymbella affininis (Table 1). The river has continuously been subject for development of more hydropower. Middle-sized rivers such as the Handölan are very important to save as a reference for future according to The Island biogeographic concept.

The Landverksströmmen (4) is located between the Lake Ånnsjön and the Lake Gevsjön. The stream site is around 30 m of width with a bottom substrate of stones and boulders and a moderate water velocity. The algal flora was dominated by the blue-green alga Nostoc spp. and the green-alga Tetraspora geletinosa and diatoms such as Achnanthes-species, Ceratoneis arcus v. linearis, the Cymbella-species, Denticula tenuis and Diatoma elongatum (Table 1). All are characteristic for northern natural rivers. The rapid is a very rich biotope for fishing and have great importance for salmon fishes like trout and char. The torrential fauna and flora are dependent of the oxygen rich water and clean flushed bottoms for their survival. The rapid should remain undisturbed.

The Tännforsen (6) was sampled in 1976. The bedrock was made of slate which itself houses sparse algal vegetation (Johansson unpubl.). The drop is 38 m and has a discharge up to 700 m3/sec. Dominating algae were Zygnemales and sparsely with diatom- species typical for fast flowing waters. The rapid is today a Natura 2000 area and as such not subject to extension.

The Tege rapids (Forsa rapids) (2) The sampling site, located close to the village of Duved, with a stream-width around 30 m, bottom substrate made of stones and boulders, non-shaded with a narrow curtain of birch forest. The site had a sparse macro-algal vegetation of the blue-green algae Tolypothrix saviczii and Gloeocapsa gelatinosa and a heavy growth of diatoms especially Achnanthes minutissima v. cryptocephala (Table 1). From the

Table 1. *The algal species per stream site, frequency of presence, species number and biomass (algal figures refer to biomass 1 - 6).*

Algae (117 species)/Sites	1	2	3	4	9	11	12	13	14	15	16	17	18	19	20a	20b	21	22	23	25	26	30	32	*freq*
Gloeocapsa gelatinosa		1																						1
Stigonema mamillosum							2													5				2
Tolypothrix distorta v. penicillata	1									6	2				4					4				5
Tolypothrix saviczii		3				2						4							1					3
Rivularia biasolettiana	1					3	2	1	1			4						2	1					8
Rivularia beccariana											4													1
Nostoc spp.				2						3	2												2	4
Phormidium autumnale												2	1		4				1		1			5
Tetraspora gelatinosa				2								2												2
Microspora membranacea														1										1
Microspora loefgreni															1									1
Microspora palustris v. minor									1															1
Chaetophora elegans					2																			1
Draparnaldia glomerata							1																	1
Chaetonema irregulare					1																			1
Oedogonium spp.						1		1			3			1	1	2	6		3					8
Bulbochaete spp.						3		1							2							3		4
Zygnema a						4																		1
Zygnema b	2		2					4			6	3				3	6						6	8
Mougeotia b															1							1		2
Mougeotia d									1															1
Mougeotia e							4										6							2
Spirogyra a				1													6							2
Spirogyra b								4						2										2
Spirogyra c																		2						1
Spirogyra d																			4					1
Batrachospermum moniliforme							1																3	2
Batrachospermum sp. (sterile)				1																				1
Melosira granulata														3				1					2	3
Melosira spp.						1																	1	2
Cyclotella comta		1																	1		1		1	4
Achnanthes linearis v. pusilla	1		1	1																				3
Achnanthes marginulata																					1			1
Achnanthes minutissima v. cryptocephala		4	3	3	4	1	3				6	3	2		4	6	5	4	5	3		5		16
Achnanthes peragalli												1									1			2
Amphipleura pellucida															1									1
Anomoeoneis brachysira	2	1				1	2	2						2										6
Anomoeoneis brachysira v. lanceolata								2	2											1				3

Algae (117 species)/Sites	1	2	3	4	9	11	12	13	14	15	16	17	18	19	20a	20b	21	22	23	25	26	30	32	*freq*
Anomoeoneis brachysira v. therminalis																		1						1
Anomoeoneis exilis			1			1							2	1	1	2	1		1					8
Anomoeoneis zellensis			1					1																2
Ceratoneis arcus							3																	1
Ceratoneis arcus v. amphioxys						1																		1
Ceratoneis arcus v. linearis	2	2	1	2	2	2	3														2			8
Cocconeis placentula											1													1
Cocconeis placentula v. euglypta										1				1	1								1	4
Cymbella affinis	4	3		4	2			2			4	4	1		2	4		4	3	3	3	3	3	16
Cymbella cesatii		2		1				2				2				2						2	3	7
Cymbella lanceolata								2			1		2	2			4	3						6
Cymbella microcephala		1		1	1	1			1			1						1	1		1		1	10
Cymbella naviculiformis																					2			1
Cymbella parva		1										1												2
Cymbella prostrata		2									2												2	3
Cymbella pusilla											1													1
Cymbella sinuata																	1							1
Cymbella ventricosa			1	3	1					1		1	1	1							2	4	2	10
Denticula tenuis				3	1				1							5				1				5
Diatoma elongatum			2	2	3						2		2		2			3	1	1		3	1	11
Diatoma elongatum v. minor					1							2	3				1	2						5
Diatoma hiemale													1		1							3		3
Diatoma hiemale v. mesodon		1																						1
Didymosphenia geminata		1	2		6										2	6	5	6	6				2	9
Diploneis elliptica										1														1
Epithemia argus												1												1
Eucocconeis flexella					2				2			1					1	2		1	3	2		8
Eucocconeis lapponica															1									1
Eunotia arcus				1					1													3		3
Eunotia pectinalis	2														2		2					3		4
Eunotia pectinalis v. minor						4	6	4	2			2							2		2			7
Eunotia pectinalis v. ventralis							2																	1
Eunotia septentrionalis									1											1				2
Eunotia vanheurckii						1																	2	2
Eunotia veneris				1																				1
Fragilaria capucina v. lanceolata										2				2	2									3
Fragilaria construens v. venter			1																					1
Fragilaria pinnata														1	1				1		1		2	5
Fragilaria vaucheriae	1	1		2													1						2	5
Frustulia rhomboides									3															1
Frustulia rhomboides v. capitata			1			3									2									3
Frustulia rhomboides v. saxonica						2																		1

Algae (117 species)/Sites	1	2	3	4	9	11	12	13	14	15	16	17	18	19	20a	20b	21	22	23	25	26	30	32	*freq*
Gomphonema acuminatum v. brebissonii				1								1		1										3
Gomphonema acuminatum v. coronata			1				1			2				1						2			1	6
Gomphonema constrictum v. capitata										1														1
Gomphonema intricatum	2		1			1		2			2			2	2		1	1	5					10
Gomphonema longiceps																								0
Gomphonema longiceps subclavata gracilis																					1			1
Gomphonema olivaceum	2																	1						2
Gomphonema parvulum					1		1														1			3
Gomphonema vaucheriae																								0
Mastogloia smithii												1												1
Mastogloia smithii v. lacustris				1																				1
Meridion circulare			1																					1
Navicula angusta																								0
Navicula contenta						1																		1
Navicula cryptocephala															1									1
Navicula exigua v. capitata				1																				1
Navicula gracilis															1									1
Navicula pseudoscutiformis		1																						1
Navicula pupula										1		1					1							3
Navicula radiosa	1	1	2	1					1				1					2			3		1	9
Navicula rotaeana	1		2														1							3
Navicula scutiformis												1												1
Nitzschia angustata																	1							1
Nitzschia angustata v. acuta					1					2				2				1			2			5
Nitzschia dissipata			1	1				1										1			1		1	6
Nitzschia kützingiana									1															1
Nitzschia linearis		1								1	1	1			1			1					1	7
Nitzschia palea																		1						1
Pinnularia appendiculata										1								2						2
Pinnularia interrupta																	2							1
Stauroneis anceps																							1	1
Surirella turgida			1																					1
Synedra ulna			3		4		3	4			5	3		5	3		3							9
Synedra ulna v. danica	1																							1
Tabellaria fenestrata									2	3		2		4	1				1	2		6	4	9
Tabellaria flocculosa	4	3	6	2	3	6	6		6	4	3			5	3			5	3	3		6		16
SUM species-number & the mean	15	18	20	22	16	19	15	15	15	14	16	22	10	18	26	8	19	21	17	12	17	13	23	**17**
SUM biomass & the mean	27	30	34	37	35	39	40	33	26	29	45	40	16	37	47	30	54	46	40	27	28	44	45	**36**

limnological as well as the ecological and landscape point of view the area is worth protecting. The rapids are also valuable to save because of the ultra-oligotrophic algal species of Tolypothrix saviczii. The theory of island biogeography should be applied and the site consequently excluded from extension.

The Mattmar stream (3) is one of the two stream channels in the Kvissle streams - at the outlet of Lake Ockesjön - and has not yet been used for hydropower.

Birch- and spruce forest occurred at the river beds. The dominating algal vegetation was made of the diatom Tabellaria flocculosa (biomass 6) together with the green alga Zygnema b (biomass 2) both typical for northern oligotrophic running waters. Another diatom, Didymosphenia geminate, recognised as greyish tufts, often growing downstream of lakes, covered the bottom to about 20% (biomass 2). Torrential algal flora was present here despite the influence of regulation (for hydropower) on the upstream located river lakes. We can here recognise the possibility to keep some adequate algal flora if enough water flow is present according to season.

The Krångede site (20b) was (and still is) heavily influenced by a hydropower plant. The water furrow contained at the sampling occasion very little water and was almost dried out. In a small rill in the middle of the furrow the diatom Didymosphenia geminata occurred together with Achnanthes minutissima v. cryptocephala and Denticula tenuis all with a biomass 5-6. The site was characterised by few species (8) with high biomass, although the total biomass was low (29) compared to the mean for all sites (36) (Table 1). This mirrors the circumstances of a disturbed running-water ecosystem and deviates heavily from a natural large river. The algal flora at this occasion reminded of a flora downstream a lake and is probably very temporarily depending on the regulated water flow due to the hydropower plant. An expansion would further aggravate the situation.

The Gammelänge site (20a) houses a hydropower plant. The site had two channels, one completely dried out and one mostly reminding of a canal with high water discharge.The algal vegetation consisted of a relatively dense mat of the blue-greens such as Tolypothrix distorta v. penicillata and Phormidium autumnale - both frequent in waters with higher current velocity and lower values of pH, conductivity and calcium than the reference curve for Jämtland (Johansson 1982a). The green algae Microspora loefgreni, Oedognium spp., Bulbochaete spp. and Mougeotia b occurred in smaller amounts (Table 1). The large diatom Didymosphenia geminata was easy to recognise as the characteristic brown tufts. An extension of the hydroelectric power (e.g., short-time regulation) would further aggravate the situation.

The Hammarforsen site (19) The samples were taken downstream the hydropower plant. Slow-flowing water of flood character occurred at the time being. A sparse flora was present of the green algae Microspora membranacea, Oedogonium spp., Spirogyra b while the diatoms Melosira granulata and Tabellaria fenestrata occurred in larger amounts due to the dam conditions. Very little remain from a river with natural flow conditions and characteristic turbulent water. An extension of the productivity of hydroelectric power (e.g., short- time regulation) would further aggravate the situation.

The Svarthålsforsen site (18) is located near Bispgården and the samples were taken downstream the power-plant at low flow. Very little was left of a torrential flora - only 10 species were present (Table 1). The only by eye visible alga was the blue-green Phormidium autumnale, typical for waters following the reference curve for Jämtland (Johansson 1982b). The river part lack a natural torrential flora due to the changed flow conditions.

The Stadsforsen site (22) - the samples were taken downstream the hydropower plant. The river had lost most characters of a natural river. The diatoms Didymosphenia geminata and Tabellaria flocculosa dominated with a biomass six and five respectively. Few threads of the blue-greens Rivularia biasolettiana and Spirogyra c was also found. Despite the regulation the site housed 21 species (mean 17) and a biomass of 46 (mean 36) although species composition typical for natural

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Birch- and spruce forest occurred at the river beds. The dominating algal vegetation was made of the diatom Tabellaria flocculosa (biomass 6) together with the green alga Zygnema b (biomass 2) both typical for northern oligotrophic running waters. Another diatom, Didymosphenia geminate, recognised as greyish tufts, often growing downstream of lakes, covered the bottom to about 20% (biomass 2). Torrential algal flora was present here despite the influence of regulation (for hydropower) on the upstream located river lakes. We can here recognise the possibility to keep some adequate algal flora if enough water flow is present according to season.

The Krångede site (20b) was (and still is) heavily influenced by a hydropower plant. The water furrow contained at the sampling occasion very little water and was almost dried out. In a small rill in the middle of the furrow the diatom Didymosphenia geminata occurred together with Achnanthes minutissima v. cryptocephala and Denticula tenuis all with a biomass 5-6. The site was characterised by few species (8) with high biomass, although the total biomass was low (29) compared to the mean for all sites (36) (Table 1). This mirrors the circumstances of a disturbed running-water ecosystem and deviates heavily from a natural large river. The algal flora at this occasion reminded of a flora downstream a lake and is probably very temporarily depending on the regulated water flow due to the hydropower plant. An expansion would further aggravate the situation.

The Gammelänge site (20a) houses a hydropower plant. The site had two channels, one completely dried out and one mostly reminding of a canal with high water discharge.The algal vegetation consisted of a relatively dense mat of the blue-greens such as Tolypothrix distorta v. penicillata and Phormidium autumnale - both frequent in waters with higher current velocity and lower values of pH, conductivity and calcium than the reference curve for Jämtland (Johansson 1982a). The green algae Microspora loefgreni, Oedognium spp., Bulbochaete spp. and Mougeotia b occurred in smaller amounts (Table 1). The large diatom Didymosphenia geminata was easy to recognise as the characteristic brown tufts. An extension of the hydroelectric power (e.g., short-time regulation) would further aggravate the situation.

The Hammarforsen site (19) The samples were taken downstream the hydropower plant. Slow-flowing water of flood character occurred at the time being. A sparse flora was present of the green algae Microspora membranacea, Oedogonium spp., Spirogyra b while the diatoms Melosira granulata and Tabellaria fenestrata occurred in larger amounts due to the dam conditions. Very little remain from a river with natural flow conditions and characteristic turbulent water. An extension of the productivity of hydroelectric power (e.g., short- time regulation) would further aggravate the situation.

The Svarthålsforsen site (18) is located near Bispgården and the samples were taken downstream the power-plant at low flow. Very little was left of a torrential flora - only 10 species were present (Table 1). The only by eye visible alga was the blue-green Phormidium autumnale, typical for waters following the reference curve for Jämtland (Johansson 1982b). The river part lack a natural torrential flora due to the changed flow conditions.

The Stadsforsen site (22) - the samples were taken downstream the hydropower plant. The river had lost most characters of a natural river. The diatoms Didymosphenia geminata and Tabellaria flocculosa dominated with a biomass six and five respectively. Few threads of the blue-greens Rivularia biasolettiana and Spirogyra c was also found. Despite the regulation the site housed 21 species (mean 17) and a biomass of 46 (mean 36) although species composition typical for natural torrential habitats were lacking (Table 1).

An extension of the productivity of hydroelectric power (e.g., short-time regulation) would further aggravate the situation.

As could be shown in this study the diatom Didymosphenia geminata was present in several of the mostly regulated rivers but also downstream lakes in unregulated waters. Blanco & Ector (2009) have thoroughly gone through many hundreds of articles including Didymosphenia from all over the world. They found that the alga increased exponentially over time and as such, causing large disaster for anglers or other negative influences of waters all over the world.

The Långan river

The Korsvatten stream (14) is located downstream the Lake Korsvattnet in the Oldfjällen area. The Lake Korsvattnet and its attached algal vegetation is well described in Quennerstedt (1955). The whole area with lakes and streams is heavily regulated for hydropower: Since the lake is regulated, the algal vegetation downstream was affected. The visible flora was very sparse at the sampling occasion which can depend on rapid changes in water fluctuation in the lake. Only a few tufts occurred of the blue-green alga Rivularia biasolettiana and the green algae Microspora palustris v. minor and Mougeotia d. The site had also a lower biomass and specie number than the average (Table 1). An expansion would further aggravate the situation.

The Rönnö rapids (8) was at the sampling occasion 1976 a broad slow-flowing river connecting Lake Rönnösjön and Lake Landösjön and yet not regulated for hydropower. The dominating algae were, at the time, the diatoms Tabellaria flocculosa, T. fenestrata, Achnanthes minutissima v. cryptocephala and the green algae Spirogyra a and Oedogonium spp. A hydropower plant was built in 2000 probably causing changed limnological situation - although not investigated in this study.

The Lång rapids (9). The bottom in the rapids was almost completely covered by two cm tufts of the diatom Didymosphenia geminata - typical for sites downstream a lake or dam. A lot of other diatoms were present such as Ceratoneis arcus v. linearis - typical for fast flowing water (Johansson 1982b) together with Cymbella affinis, other Cymbellas and Eucocconeis flexella. All adequate for fast running waters. An extension of hydropower will probably eliminate the rapids and the conditions for a torrential natural flora and fauna. According to the theory of island biogeography concept the site is worth saving.

The Hårkan river

The unregulated Tosk stream (10) connects the Valsjö lake with the Hotagen lake close to the Norwegian border. The rapids are famous for its downstream spawning trout. The site was sampled in 1975 and the algal vegetation was dominated by the green algae Oedogonium spp. and Zygnema b as well as the diatoms Tabellaria flocculosa, Ceratoneis arcus v. linearis - typical for fast-flowing waters - Synedra ulna and Tabellaria fenestrata - the latter typical as drift from upstream located lakes or dams. The rapid is worth saving by many reasons although the theory of island biogeography concept is most applicable for the attached algae.

The Eds rapids (25) are one of very few other rapids left in the regulated River Hårkan and as such an area also important for fishing. The algal vegetation was dominated by blue-greens such as Stigonema mamillosum and Tolypothrix distorta v. penicillata (biomass 5 and 4) and to a lesser degree diatoms (table 1). The Stigonema is typical for middle sized and larger streams with rapid water and high insolation, non-calcareous and low values of conductivity (Johansson 1982b). Dominating diatoms were Achnanthes minutissima v. cryptocephala, Cymbella affinis and Tabellaria flocculosa (biomass 3). All are expected in high quantities in fast-flowing waters (Johansson 1982b). The Hög rapids (26) site is located in the dam just upstream the hydropower plant. The macro algal flora typical for running turbulent waters was absent - only single threads of the blue- green alga Phormidium autumnale occurred. Diatoms such as Cymbella affinis, Eucocconeis flexella, and Navicula radiosa dominated with a biomass 3. The species number were 17 as the mean for all sites and biomass much lower than the mean (Table 1). An extension of the hydropower would probably aggravate the situation.

The Ammer river

The whole river is protected against hydropower. The river has also become a 60 km long Nature Reserve from the Lake Solvattnet down to the outflow into the Indal river.

The Storå stream (11) at the outflow of the Lake Lillfulvuren was characterised by a large biomass of macro algae such as the blue-greens Tolypothrix saviczii and Rivularia biasolettiana and the green algae Zygnema a, Bulbochaete spp. and Oedogonium spp. In addition, the diatom Tabellaria flocculosa also occurred in great amounts. Other frequent diatoms were Eunotia pectinalis v. minor - indicating acid water - Frustulia rhomboides v. capitata - frequent in waters with pH <7 and very low values of conductivity and calcium (Johansson 1982b). The stream is unregulated and of ultra-oligotrophic state with species present for such conditions such as Tolypothrix savizcii and Rivularia biasolettiana. Located in a nature reserve, it is not dated for action.

The Storå stream (12) further downstream at Lakavattnet was dominated by a high total biomass (40) of algae on the stone- and boulder bottom. The site was surrounded by spruce forest on both sides with isolated dwellings. In the moderate running water a large biomass (4) of the green alga Mougeotia e occurred together with somewhat lesser degree (2) of the blue- greens Stigonema mamillosum and Rivularia biasolettiana. Dominating diatoms were the Eunotia pectinalis v. minor - indicating acid water and Tabellaria flocculosa - found in almost half of the sites, is typical for northern waters and was present in 50% of all the studied waters (500) in the County of Jämtland (Johansson 1982b). The stream site is worth saving - although not as ultra-oligothrophic as the foregoing.

The Hökvatten stream (13) is a tributary to the Storå stream and the site was located in a small dwelling area. The water dynamics was varying with river-lakes, rapids and fall. The site had a rather high biomass of green algae such as Zygnema b and Spirogyra b. The dominating species of diatoms were Eunotia pectinalis v. minor and Synedra ulna both with a biomass 4. The absence of Achnanthes minutissima v. cryptocephala - normally present in 2/3 of all sites and following the reference curve for Jämtland - and the presence of Anomoeoneis brachysira and A. brachysira v. lanceolata was interesting. The latter prefer waters with lower values for pH, conductivity and calcium than the reference curve for Jämtland (Johansson 1982b). Also, the absence of Tabellaria flocculosa - present in 2/3 of the sites - may indicate acidicy of the site - Tabellaria flocculosa prefer waters following the reference curve for Jämtland (Johansson op cit). The site is located in a Natura 2000 area (including the presence of the clam Margaritifera margaritifera) and as such not dated for action. The Springhällarna (32) is a site downstream the Lake Fyrsjön in the unregulated River Ammerån. The abundant algal vegetation consisted mostly of the green alga Zygnema b but also a great deal of the red alga Batrachospermum moniliforme and the blue-green alga Nostoc spp. The site was one of the most species-rich (23) and with high biomass (45) sites in this study (Table 1). The Melosira species, Didymosphenia geminata and Tabellaria fenestrate were dominating due to the location downstream the lake.

The Borg rapids (21) site is located south of Skyttmon. The site is frequently visited by fishermen. The bottom substrate of cliffs and boulders was almost covered by different species of green algae all with a biomass 6, such as Oedogonium spp., Zygnema b, Mougeotia e and Spirogyra a and large tufts (biomass 5) of the diatom Didymosphenia geminata. The biomass was the highest (55) among all sites. The turbulent water and high insolation (little shade) give good circumstances for a torrential algal flora. The site should be preserved as refuge for the future as well as the whole Ammer river according to theory of island biogeography concept.

The Ljungan river

The Sölvbacka rapids (23) are located in the Ljungan river downstream the Lake Storsjön as such: The rapids are 6-7 km with a drop of 60 m - one of the few rapids left in the river. The dominating

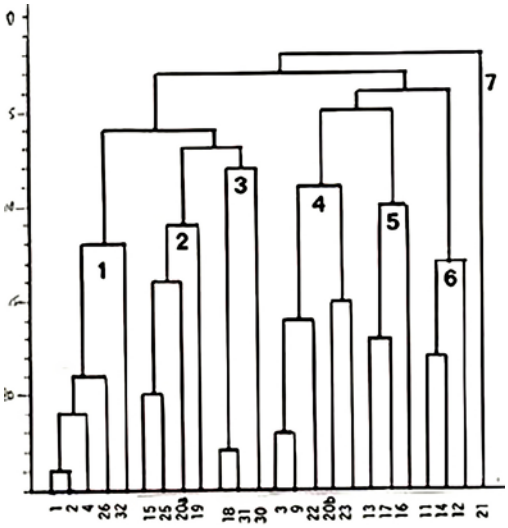

Figure 1. *Sites: 1 Handöl, 2 Tegeforsen, 3 Mattmar, 4 Landverksströmmen, 9 Långforsen, 11 Storån at Lillfulvurn, 12 Storån at Lakavattnet, 13 Hökvatten stream, 14 Korsvattenån, 15 Broforsen, 16 Glissjöberg, 17 Linsellborren, 18 Svarthålsforsen, 19 Hammarforsen, 20a Gammelänge, 20b Krångede, 21 Borgforsen, 22 Stadsforsen, 23 Sölvbackaströmmarna, 25 Edsoxforsen, 26 Högforsen, 30 Flåsjöån, 31 excluded, 32 Springhällarna.*

algae were the green algae Oedogonium spp. and Spirogyra d (biomass 3 and 4). Didymosphenia geminata was the dominating diatom (biomass 6) together with Tabellaria flocculosa and Achnanthes minutissima v. cryptocephala (both biomass 5). The foregoing alga was found typical for lake or dam outlets (Johansson 1982b). The rapids are protected against hydropower since the end of 1990th.

The Ljusnan river

Below the Nature reserve including 15 km of the River Ljusnan is illustrated. This is also the only part of the river not used for hydropower. The rapids are although heavily affected by changes in the river flow due to hydropower plants further upstream.

The Bro rapids (15) is the uppermost part in the Nature reserve - see above. A rather dense vegetation of the blue- green algae Tolypothrix distorta v. penicillata and Nostoc spp. covered the bottom and as a result of this a sparse flora of diatoms was present - the dominant species were Tabellaria flocculosa and Tabellaria fenestrata - the latter typical for sites downstream lakes as is the case here. The site had a biomass and species number below the mean for all sites probably due to regulation upstream. The Ljusnan river houses 22 hydropower plants and together with all tributaries 44 plants exists.

The Linsellborren (17) is also a pleasant part of the River Ljusnan located downstream the Bro rapids. A moderate growth occurred by the macro-algae such as the blue-greens of Rivularia biasolettiana and Phormidium autumnale together with the green algae Zygnema b and Tetraspora gelatinosa. The diatoms were dominated by Cymbella affinis, C. cesatii, C. microcephala, C. parva and C. ventricosa. Both the species number and the biomass were somewhat higher than the average for all the 24 sites studied (Table 1). The site is popular for fishing trout and grayling.

The Glissjöberg or the Sand rapids (16) are the last rapids of the three. A large biomass of algae was available (total biomass 45). Small compact crusts of the blue-green Rivularia beccariana together with Tolypothrix distorta v. penicillata and Nostoc spp. grew on boulders and cliffs. R. beccariana was rarely found in Jämtland during the mid 1970th. Tolypothrix above preferred streams with lower pH, conductivity and calcium than the reference curve for Jämtland (Johansson 1982b). The total biomass (45) was a bit larger than the mean (36) while species number was close to the mean (Table 1).

Cluster analysis and polar ordination

The two statistical methods used were cluster analysis and polar ordination for illustrating the relationships between the studied stream sites. In all clustering procedures it is essential that the entities within a group show more likeness to each other than to entities of other groups. Numerous ways of expressing the degree of association between two entities (here sites) are available. A CLUSTER analysis according to the Statistical Analysis System (SAS) was used and no a priori or theoretical classification of the data set was applied beforehand.

The regional variations in species composition were also studied applying the technique of polar ordination (Poole 1974). A common correlation matrix between sites was established. From this the stations with the highest negative correlation have been taken out to be used as the outermost points to which the others were related and shown in a diagram. The cluster analysis (Fig. 1) based on algal composition gave seven clusters as such (figures along the x- axis represent the site-number and figures along the y-axis represent number of clusters):

Below a description and analysis per cluster is given. Grouped sites lower in the diagram are more alike (according to algal composition) than upwards. Cluster 1 was characterised by sites (1, 2, 4, 26, 32) located in broad natural rather fast-flowing streams with an algal flora typical for northern waters. The algal vegetation was characterised by a macro-algal cover composed of blue-greens and green algae. Common for two of the sites (4, 32) was also the red alga Batrachospermum spp. The diatoms common for sites 1, 2, 4 and 26 were Ceratoneis arcus v. linearis and Navicula radiosa - both typical for fast-flowing streams and high insolation and found in every 5th stream in Jämtland (Johansson 1982b).

Cluster 2 included two large rapids (15, 25) in an otherwise regulated river and two sites (20a, 19) just downstream hydropower plants in the Indals river - although hocked to the cluster later in the process - see figure above. Common for three of the sites (15, 25, 20a) was the high biomass of the blue-green alga Tolypothrix distorta v. linearis - typical for water courses with lower pH, conductivity and calcium than the ref curve for Jämtland (Johansson 1982b). Common for the sites 15 and 25 was the occurrence of few species and low biomass. The regulated sites 19 and 20a had in common the presence of Synedra ulna in rather high biomass. S. ulna is typical for waters with slightly higher pH and conductivity than the reference curve for Jämtland and significantly found in streams with higher discharge than the average for Jämtland (Johansson 1982b).

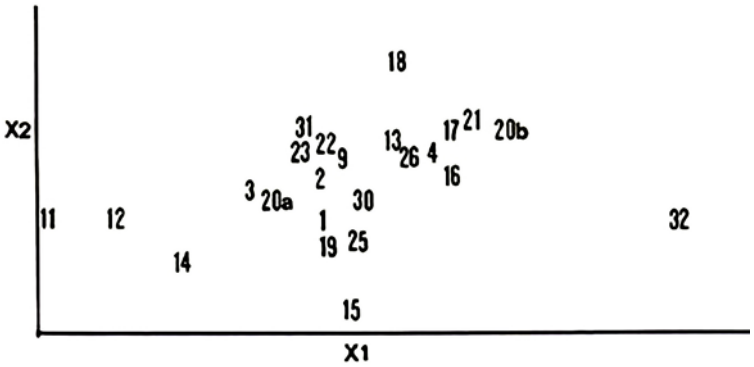

Figure 2. *Polar ordination of 23 stream sites in the Jämtland County, mid-Sweden. Sites: 1 Handöl, 2 Tegeforsen, 3 Mattmar, 4 Landverksströmmen, 9 Långforsen, 11 Storån at Lillfulvurn, 12 Storån at Lakavattnet, 13 Hökvatten stream, 14 Korsvattenån, 15 Broforsen, 16 Glissjöberg, 17 Linsellborren, 18 Svarthålsforsen, 19 Hammarforsen, 20a Gammelänge, 20b Krångede, 21 Borgforsen, 22 Stadsforsen, 23 Sölvbackaströmmarna, 25 Edsoxforsen, 26 Högforsen, 30 Flåsjöån, 31 excluded, 32 Springhällarna.*

Cluster 3 included only two sites (31 was deleted) both regulated for hydropower. The sites clustered at a high level - se figure above - which indicate that species similarities were low. Although, both sites had very few species 10 and 13 respectively compared to the mean and the common diatoms were mostly Cymbellas. Both sites also lack the typical torrential species.

Cluster 4 included three sites of broad unexplored rapids such as the Mattmar stream (3), the Lång rapids (9) and the Sölvbacka rapids (31) and two sites downstream hydropower plants such as the Krångede site (20b) and the Stadsforsen (22) (both in the Indal river). How could that be possible? The analysis grouped the five sites mainly due to the high biomass of the tuft- building diatom Didymosphenia geminata - an alga found in both regulated and unregulated waters often below dams or river lakes (sel). The Krångede site (20b) was the most disturbed one with very few species. Ceratoneis arcus v. linearis - indicating turbulent rapid water - was probably the main reason for clustering the two rapids 3 and 9.

Cluster 5 including three sites characterised by rapids without hydropower plants - the Hökvattnet stream (13), the Glissjöberg rapids (16) and the Linsellborren rapids (17). High biomass of Zygnema b - typical for dynamic turbulent waters - and Synedra ulna - typical for waters with high discharge often downstream river lakes - clustered the sites. Eunotia pectinalis v. minor probably clustered 13 and 17.

Cluster 6 including the Storå stream at Lillfulvurn (11), the Korsvatten stream (14) and the Storå stream at Lakavattnet (12), all located in source areas. The Korsvatten stream is affected by regulation for hydropower. The algae based for clustering the sites were the high biomass (6) of the diatom Tabellaria flocculosa, the moderate biomass of Eunotia pectinalis v. minor and the blue-green alga Rivularia biasolettiana. The three species prefer waters with lower pH, calcium and conductivity and higher insolation than the reference curve for Jämtland (Johansson 1982a, Johansson 1982b).

Cluster 7 consisted of only one site - the Borg rapids (21) in the Ammer river - protected against hydropower. The site was, as the only one in the study, characterised by a heavy growth of four green algal species - all with the biomass 6 which made it outstanding compared to the other sites. The algae Oedogonium spp., Zygnema b, Mougeotia e and Spirogyra a were all in the study of Jämtland preferring waters with lower conductivity and higher insolation than the reference curve (Johansson 1982b). In addition the diatom Didymosphenia geminata occurred with a biomass 5. The stream part is famous for good trout fishing.

The cluster analysis made ”good” grouping of sites according to parameters such as water flow, insolation, substrate and regulation for hydropower. Although the analysis grouped sites below hydropower plants together with sites from rapids - mainly at a lower clustering level - are probably due to high water discharge conditions. Genuine torrential species react very fast and intense (high biomass) on such circumstances (Johansson 1982b).

The polar ordination (Fig. 2) gave the following presentation with site 11, 15, 18 and 32 as the outermost sites to which the others has been oriented along the X-1 and X-2 axis, where 11 represent a natural alpine stream without regulation, 15 rapids in between regulated river- lakes, 18 a heavily regulated river and 32 rapids in an unregulated river

The Storå stream at Lillfulvurn (11) represent a typical natural site in the uppermost parts of the unregulated river Ammerån with an algal vegetation expected for torrential habitat. The Broforsen rapid (15) in the Ljusnan river represent a torrential part in a Nature reserve although affected by regulation from above located dam. The Svarthål rapid (18) - a site downstream a hydropower plant in the heavily regulated Indal river - was composed of a very damaged algal flora far from the expected for natural northern areas. The Springhällarna site (32) in the unregulated Ammer river included typical torrential attached algal flora although heavily affected by diatoms typical for lakes - the reason for its location far out to the right in the diagram.

Consequently, sites located upwards in the diagram have a more or less damaged attached algal flora. Sites to the left in the diagram are charac-

terised by a typical mostly undisturbed torrential flora. Downwards are found broad water courses with a slightly disturbed torrential flora and to the right in the diagram the Springhällarna site (32) in the Ammer river - characterised by a diverse algal flora with many torrential species and a total high biomass. In addition, the site housed the red alga Batrachospermum moniliforme - only found in two other sites which also make the site isolated in the diagram.

Discussion

The attached algal (periphyton, benthic algae) community gave a good picture of the state of the stream site. The deviation from undisturbed streams sites was most conspicuous downstream hydropower stations where the typical torrential flora was missing or degraded. Least damaged was the sites where rapids remain. The deviation from natural is always connected with the stream flow - the influenced by regulation the more aggravated. Some sites downstream dams could however present a lot of species and a large biomass but with other species than the genuine lotic ones. For most sites where rapids still exist my recommendations will be no more extension - some of the sites has also become protected during the last 10 - 20 years.

The cluster analysis and the polar ordination gives an adequate overview of how the different sites are connected according to benthic algae. Sites with species and biomass well different from the others are clearly visible and sites with small differences are grouped together at different levels. When dealing with a lot of sites - which often is the case for characterisation of streams - the two analyses are of great value to structure the data set and make conclusions somewhat faster. I have here focused on the island biogeographical concept as a good theory to evaluate different places over others. I think it gives a summary assessment of what biodiversity is all about - to keep ecosystems for coming generations with enough generic material for survival. The approach of using species biomass presents the success for each species and the algal community during the growth period and give a diagnosis of the ecological status of the site or stream stretch. A high or low biomass can indicate either good or bad conditions according to expected for the river or stream in question. Just presence-absence data of species does not at one single sample occasion give the same reliable result.

Recommendations

Taking into account both the species composition and the clustering and polar ordination the different sites have been classified according to action or protection into four classes. Altogether the species number and the evaluation of biomass, both total and for each species, gives the necessary input for the consideration of how far or close to natural the site in question is. The clustering and ordination analysis help to show the connection between sites and with basis of algal requirements it is possible to make up the recommendations below.

Class 1 Water courses or stretches which should be left undisturbed mainly due to the ”island biogeography concept”.

- The Handölan stream (1) The Tännrapids (6)
- The Storå stream (at Lillfulvurn) (11) The Borg rapids (21)
- The Sölvbacka rapids (23) The Springhällarna (32)

Class 2 Water courses or stretches which not definitively can be brought to class 1 but should be restricted from development of waterpower.

- The Tege rapids (2)
- The Landverk rapids (4) The Lång rapids (9) The Tosk rapids (10)
- The The Storå stream (at Lakavattnet) (12) The Bro rapids (15)
- The Gissjöberg (16)
- The Linsellborren (17) The Edsox rapids (25) The Lejar river (29)

Class 3 Water courses or stretches that have moderate algal vegetation and/or frequently used by anglers or have other tourist attraction - can be regulated if water flow do not deviate too much from natural.

- The Mattmar rapid (3)
- The Rönnö rapid (8) new waterpower plant year 2000 The Hökvattnet tributary (13)
- The Korsvattnet stream (14) The Flåsjö stream (30)

Class 4 Water courses or stretches that are of little limnological value which means that the natural algal flora has more or less been lost - can be extended for hydropower although not short-time regulation.

- The Svarthåls rapid (18)
- The Hammar rapid (19)
- The Gammelänge (20a)
- The Krångede (20b)
- The Stads rapid (22)
- The High rapids (26)
- The Hocksjö (31)

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