Long-term monitoring to assess the benefits of stream frontage management to ecological condition of the Campaspe River, Victoria Australia

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Key Points

- Willows reduce river ecological health by impacting on water and habitat quality
- Understanding the benefits of Stream Frontage management Works to ecological health requires an understanding of all pressures impacting river health
- Both habitat and water and sediment quality affect the ecological health of waterways.

Abstract

Coliban Water has funded a further 14.3-kilometre section of the North Central CMA's "Caring for the Campaspe" stream frontage management program (SFMP). Designed to improve the ecological condition of the Campaspe River by improving riverside vegetation, the program removes willows and revegetates riparian land with native plants and provides fencing to exclude stock from the river corridor. The AQUEST research group, from RMIT University, was engaged by Coliban Water to assess the environmental benefits of this program to river health.

To assess the benefits of the SFM works to river health, a variety of indicators including water quality, aquatic ecology (macrophytes, algae and macroinvertebrates), nutrient availability, and ecotoxicology are being monitored at 8 sites along the Campaspe River, from Carlsruhe to Redesdale. Monitoring is being conducted yearly over a 5-year period, targeted to periods when the river is flowing, as in the study area the River is ephemeral, particularly during the summer period.

The first 2-years of monitoring show some sites are physically in very poor condition, with poor water quality and aquatic ecology; while other sites are in good condition, dominated by native vegetation with good water quality and aquatic ecology. Several pollutants were present including elevated nutrients, heavy metals and several pesticides. The major contributors to sites in poor condition, were the lack of quality habitat, urban, agricultural, and industrial runoff, and treated and untreated wastewater inputs.

This program shows how using a variety of physical and ecological indicators can provide a greater understanding of river health and the majors factors influencing it.

Keywords

Stream Frontage Management, willows, ecological monitoring, river health

Introduction

Over the past two decades government agencies, water authorities and community groups have invested significant resources in stream frontage management (SFM) interventions along waterways, such as weed management, revegetation, erosion planting and stock management fencing to improve vegetation condition, manage bank erosion, reduce the export of pollutants to waterways, and contribute to long-term improvements in water quality and instream conditions (Cottingham et al 2005; DEWLP 2018). While investment into these rehabilitation measures is high, monitoring and reporting of their effectiveness in improving ecological health of waterways is rarely undertaken (Cottingham et al 2005; DEWLP 2018).

Riparian vegetation plays an important role in the health of waterways. It can support a diverse range of native plants and animals and provides important ecological functions, including improving water quality by filtering nutrients, pollutants and sediments; stabilizing banks; and providing food and habitat for both terrestrial and aquatic animals. However, riparian land is frequently degraded by clearing, invasive plants, such as willows, and livestock grazing, resulting in decreased ecological health of waterways (Cottingham et al 2005).

The “Caring for the Campaspe” project is the first large scale on-ground works project to deliver river health improvements for the Campaspe River from its headwaters near Ashbourne to the Murray River at Echuca. The overall goal of the project is to improve the condition of riparian vegetation leading to improvements in the aquatic and riparian ecosystem health of the Campaspe River. As part of the caring for the Campaspe program, Coliban Water provided additional funding to the NCCMA to undertake a further 14.3km of environmental improvement work along the River, from Carlsrhue to below Kyneton. Works included the removal of willow trees, blackberries, hawthorns and other weeds, and revegetating with native trees and shrubs, installing 13.1km of fencing to keep livestock out of the waterway, installing off-stream watering systems as an alternative water source for livestock and supplementary replanting, weed control and revegetation watering. Restoration works commenced in April 2019 and were completed in December 2019 and are now being maintained.

To assess the environmental benefits of the SFM works to the Campaspe River, Coliban Water engaged the Aquatic Environmental Stress Research Group (AQUEST), from RMIT University to undertake a 5-year monitoring program. The major focus of the monitoring program is to measure changes in ambient water quality, particularly nutrients, indicators of faecal contamination and physico-chemistry; together with measures of instream plant growth and macroinvertebrate diversity. However, the effectiveness of improvements in riparian habitat for aquatic animals can be constrained if other factors, such as presence of pollutants other than nutrients are present and impacting on ecological health. Thus, the program aims to understand whether wider activities may be influencing water quality and instream health through assessments of water and sediment chemistry and ecotoxicology.

Methods

Study Area

The 5-year monitoring and assessment program is focused on the Upper Campaspe River from Carlsruhe to Redesdale, which runs through agricultural, residential, and industrial areas. Stream Frontage Management Works were targeted at four locations along the Campaspe River. These works included initial woody weed control, revegetation, fencing and off stream watering installations, which were undertaken from April 2019 to December 2019; followed by weeding, supplementary watering and revegetation maintenance programs commencing in Spring/Summer 2020 and continuing to Spring/Summer 2023. Eight sites along the Campaspe River were selected to assess the benefits of the SFMW and understand other factors influencing stream health. Sites 1-5 were selected to represent different stages in SFMW (Site 1 recent willow removal and stock exclusion; Site 2, >10yrs since willow removal and stock exclusion; Site 3-5 <2yrs since willow removal, revegetation and stock exclusion), while Site 6 was a willow control site and Sites 7 and 8 native vegetation controls.

Monitoring Program

To assess the benefits of the SFM works to river health and understand other factors that may influence river condition, a variety of indicators including water and sediment chemistry, aquatic ecology, physical habitat condition and surface water toxicity are being monitored. Samples are collected annually from all eight sites at five time points, targeted when the river is flowing, to assess seasonal trends. During Year 1 monitoring was conducted from September through December 2018 and in July 2019, while for Year 2 monitoring was conducted from August to December 2019.

The monitoring methods applied are summarized in Table 1, with detailed methods available in Myers et al 2019.

Table 1. Summary of monitoring methods.

Indicator	Description

Surface Water Chemistry	
Physico-chemistry	Parameters included water temperature, dissolved oxygen (% saturation), pH, electrical conductivity and turbidity measured monthly.
Nutrients	Water samples analysed for ammonia as N (NH_4-N), total nitrogen (TN), total Kjeldahl Nitrogen (TKN), nitrate and nitrite (NOx), orthophosphate (OP) and total phosphorus (TP) monthly.
Faecal monitoring*	Escherichia *coli* was used as the key indicator of faecal contamination and *Bacteroides* spp. assay was used to determine the origin (e.g., human, bovine). Samples are collected on 3 occasions.
Passive samplers	Polar Organic Chemical Integrated Samplers (POCIS) were deployed at each site once for a 4-week period to detect pollutants including personal care products, pharmaceuticals, herbicides, insecticides and fungicides present in surface waters.
Sediment Chemistry	
Sediment chemistry	Heavy metals, petroleum hydrocarbons and multi-residue pesticides were analysed from fine (<4µm) sediment samples collected annually.
Aquatic Ecology	
Macroinvertebrate survey	Rapid Bioassessment (RBA) method applied annually. Collection and identification took place according to EPA Victoria guidelines (EPA Victoria, 2003). Biological indices (number of families, SIGNAL and EPT indices) determined.
Benthic algal production	Thin discs were suspended, in triplicate, in the water column for a 4-week period bi-annually. These artificial substrates were analysed for biofilm biomass (measured as AFDM and chlorophyll-a).
Physical habitat	
Instream habitat assessment	Percentage cover of aquatic macrophytes and filamentous algae (>2cm) is measured monthly.
Surface Water Toxicity	
Floral toxicity	The growth of algae immobilised in alginate beads, was used to assess the toxicity of surface waters to floral species. Algal beads were deployed in cages for 10 days, thereafter biomass determined bi-annually.
Faunal toxicity	The survival and reproductive ability of the mud snail, *Potamopyrgus antipodarum* was used to assess surface water toxicity. Snails were deployed in cages for 4 weeks annually.

* Undertaken at five sites (sites 2, 4, 5, 6, and 7)

Results and Discussion

Physical River condition

The stream frontage management works began in February 2019. Initial woody weed control (56 ha) and revegetation (15 ha) was undertaken from April to October, and September to November 2019, respectively. Livestock exclusion fencing (113.1 km), and offstream watering works began in August 2019. At the end of Year 2 monitoring (December 2019), most works across all SFM sites were completed and sites are in the maintenance phase of the project.

The principle focus of the SFM program is a reduction in the delivery of sediment, nutrients, and pathogens to the River. While the benefits from SFM are not likely to be observed in 2 years of monitoring, early results show evidence of differences in river condition based on riparian condition. Sites 1 and 6, where willows dominate the riparian, were generally characterized as having higher levels of dissolved nutrients (TN, TP, Orthophosphate), lower dissolved oxygen levels and water temperatures, and poorer water clarity, as measured by turbidity (Table 2). Historically, willows have been used to control riverbank erosion, proving to be very successful due to their rapid vegetative growth and thick root matt (Bobbi 1999). However, it's now recognized they cause significant impacts to river health. Willows contribute a large amount of leaf litter to streams over a short period, which is very different to native species which have a more continuous leaf fall (Lester et al., 1994). In situations where they invade the entire riverbanks and bed, they shade the entire river, reducing water temperatures, and increasing the retention of sediments, as well as organic material, which reduces aquatic habitat and stimulates bacterial activity. This also leads to increases in instream nutrient concentrations (Bobbi 1999). In addition, disturbance caused by willow removal may temporarily increase nutrient and sediment inputs with impacts on nutrient levels observed for up to five years (Wagenhoff & Young, 2013).

In comparison, sites dominated by established native vegetation, such as Sites 7 and 8, had a healthier and more stable water quality (Table 2). Elevated levels of nutrients were observed (Table 2), however, this is likely due to other factors occurring in the catchment (See discussion of other factors influencing river health) and, to a lesser extent, riparian condition. Sites 3, 4 and 5, where willow removal and revegetation has occurred within the last 2 years, showed similar water quality to that of established native riparian sites, although some measures show variability. For instance, water temperatures vary considerably (Table 2), possibly because of a lack of riparian canopy to provide shade. Similarly, turbidity is variable (Table 2), with a lack of an established riparian zone? to filter runoff a possible explanation. As the plantings become more established at these sites, it is predicted these factors will become more stable.

Unrestricted stock access to waterways is a factor well known to contribute nutrients and sediments to waterways, as well as faecal contamination (Biggs 2000; Shearman and Wilcock 2011; Hughes and Quinn 2014; McKergow et al 2016). Stock typically graze pasture to the water's edge, damaging the banks, and with no physical barrier to runoff, faeces, urine and nutrients enters waterways more freely when it rains (Shearman and Wilcocks 2011). When faecal matter is found in water, it's indicative of the potential for harmful pathogens to also be present (Ministry for the Environment, 2001; Shearman and Wilcock 2011). Stock have unrestricted access to the river at Sites 1 and 6, while they graze on adjacent land at Sites 2, 4, 5, 7 and 8. _Escherichia coli_ were observed in both monitoring years at the subset of sites monitored, however exceeded guideline values (100 organisms per 100mL) at Sites 2 and 6 (Table 2). However, _E. coli_ is a general marker of faecal contamination in waterways and cannot be linked to a particular source. To provide a better understanding of the sources of faecal contamination, markers for the presence of _Bacteroides_ spp., a bacterium that inhabit the digestive tracts of animals, were applied. The markers indicated faecal contamination, attributable in part to stock, occurred at Sites where stock graze adjacent to the river with restricted access (2, 4, and 8) and at Site 6 where stock have unrestricted access (Table 2).

Aquatic macrophytes and algae are important structural and biological components of rivers. Healthy macrophyte and algal assemblages support ecosystem health by processing stream nutrients and providing habitat and food resources for aquatic biota (Paice et al 2017). However, excessive growth can lead to choking of the channel, reduced light, low oxygen, and poor habitat and food resources (Rutherford and Cuddy 2005; McKergow et al., 2016). Visual assessments of macrophyte and filamentous algal growth were undertaken to assess the level of nuisance algal and plant growth. Nuisance levels, particularly for filamentous algae, are reached at 30% of stream bed coverage (Biggs 2000). For all sites, except for Site 8, macrophyte cover was greater than 30%. Over the 2 years, cover remained stable across Sites 3-8, however at Sites 1 and 2, substantial increases in macrophyte cover were observed (Table 2). The presence of filamentous algae (>2cm length) was generally less than 30% at all sites, except for Sites 5 and 7, where cover reached 31% and 44%, respectively in Year 1 (Table 2). Overall, there was a decline in filamentous algal cover at all sites from Year 1 to Year 2 (Table 2), which is likely related to decreases in available nutrients, particularly phosphates at sites (Table 2).

Macrophyte and algal abundance is generally strongly correlated with light and nutrient availability (Biggs 2000; Rutherford and Cuddy 2005). Riparian canopy plays an important role in reducing water temperatures and controlling nuisance plant and algal growth through provision of shade (Hughes and Quinn, 2014; McKergow et al., 2016). In general, observations of macrophyte cover during the first 2 years show a higher abundance (>50% cover) at sites with less riparian shade cover (Sites 1-4; Table 2). However, high abundance of macrophytes were also observed at sites with high shade cover (>60%; Sites 6 and 7; Table 2). At these sites there was a change in the species composition from rooted submerged and emergent macrophytes, such as _Myriophyllium_ Sp., to floating macrophytes such as _Azolla_ Sp. The high abundances are thus likely related to nutrient availability, notably orthophosphates, at these sites. In time, a better balance in macrophyte abundance is likely to occur in reaches around Sites 1-4 as new plantings grow and the level of shade increases. However, for sites where elevated nutrients are likely to be driving macrophyte cover, such as Sites 6 and 7, improvements to riparian cover or reductions in nutrient inputs may be needed to better balance macrophyte abundance and reduce filamentous algal growth. Too much shade by riparian vegetation can result in reduced nutrient uptake by in-stream macrophytes, tipping the balance between nutrient uptake and export (Hughes and Quinn, 2014; McKergow et al., 2016). Heavy shading by willows at Site 6 has contributed to reduced light for macrophytes and filamentous algal production. This results in little instream processing of nutrients and greater export to downstream reaches, which is reflected in elevated nutrient levels and excessive filamentous algal growth observed at Site 7. Site 6, thus presents great opportunities for SFM works to improve river health along that reach and further downstream.

Other catchment impacts

To achieve overall improvements in river water quality and biodiversity, an understanding of all factors impacting waterway health across the catchment is required. Monitoring of several pollutants in surface waters and sediments, paired with toxicological assessments, provides us with an understanding of different pressures influencing waterway health. Several additional pressures were detected across the study area, including the presence of toxicity and a range of pollutants associated with wastewater inputs, and urban, industrial and agricultural runoff.

In addition to agricultural runoff, nutrients may enter rivers from urban runoff and wastewater, from both treated discharges and septic leakages. Inputs from these sources are observed in the River at Sites 1, 2, 6 and 7. In addition, the detection of human *Bacteroides* spp. markers and several pharmaceuticals in surface waters further indicates wastewater contributions to the River (Table 2).

Urban, industrial and agricultural runoff can result in the contribution of various pollutants to waterways, particularly heavy metals, hydrocarbons and pesticides. The occurrence of heavy metals and hydrocarbons is usually related to anthropogenic activities, such as rail and road transport, industrial activities (e.g.: metal recyclers, old mining) and housing (e.g.: zinc roofing). These pollutants have the potential to impact on aquatic ecosystem health, reducing biodiversity and causing toxicity to both flora and fauna. Several heavy metals, including zinc, mercury and lead have been detected at concentrations of concern for aquatic life (Table 2). Additionally, hydrocarbon concentrations were elevated across most sites, particularly those directly surrounded by heavy traffic roads and rail tracks (Table 2).

Pesticides enter waterways via various pathways, including surface runoff during irrigation and/or rainfall, aerial deposition via spray drift, and via infiltration from groundwater. Several pesticides have been detected, including six herbicides and two insecticides and two synthetic pyrethroids insecticides in surface waters and sediments, respectively (Table 2). The detection of pesticides across all study sites suggests applications across a range of land uses e.g.: agricultural, urban and industrial are contributing to pesticide contamination. Algal toxicology assessments indicate some of these pesticides, particularly the herbicides, are at levels that may be adversely impact stream biodiversity, with moderate growth inhibition (20-50% inhibition) observed across most sites (Table 2).

Faunal toxicity was observed at the willow dominated Site 6 during both monitoring years (Table 2). It is likely that the low dissolved oxygen, reduced water temperatures and overall poor habitat condition due to choking by willows at this site contributed to the poor snail survival. It is also possible the presence of other pollutants added to the observed toxicity. Continued monitoring of the occurrence of these ‘other’ pollutants and measurement of faunal and floral toxicity provides a greater understanding of potential risks posed to river health, and a better understanding of their sources, so that priority management actions can be identified.

Ecological condition

Assessments of macroinvertebrate communities provide a picture of ecological health in the River, with increased richness and diversity indicating better water quality and better ecological condition. Signal scores as well as the diversity of families and the presence of sensitive taxa, indicate that, in general, the Campaspe River is in a moderate condition, related to a certain extent, to the river being an ephemeral system, and, thus, without a permanent water source, macroinvertebrates must recolonize sites each year.

Sites in the mid reaches of the study area (Sites 3-5), where SFMW were completed in the last 2 yrs, show highest diversity of macroinvertebrates and include the greatest numbers of sensitive taxa (Table 3). These sites, while not having a developed riparian cover, have a diversity of instream plants providing good habitat structure for invertebrate communities. Similarly, the two sites dominated by native riparian (Sites 7 and 8) generally had good habitat available for macroinvertebrate communities; however, they also showed signs of nutrient enrichment and possible impacts from aquatic pollution. Poorest ecological health, however, was observed at sites where recent willow removal had occurred, or where willows still dominate the riverbanks and bed (Sites 1 and 6; Table 3). Willows are known to restrict the number of macroinvertebrate taxa (Lester et al., 1994; McInerney et al., 2016), as a result of increased nutrient concentrations, and a lack of a continual supply of organic matter of appropriate quality as a food source, which is clearly seen at Site 6 with a reduced number of taxa and species that are indicative of organic enrichment and poor habitat.

In time, for sites such as Site 1, where willow removal has occurred, as revegetated areas establish, we are likely to see improved instream habitat and food resources, and improvements in macroinvertebrate diversity and richness will likely also occur.

Conclusions

The initial two years of monitoring has provided information from which to assess the short-term benefits of the SFMW to the Campaspe River, and provided insight into other factors influencing river health. Benefits of the SFMP will continue to be seen over the next few years as initial impacts from willow removal dissipate and riparian vegetation becomes more established. Immediate benefits have started to present at sites where willow removal occurred within the last 2 years, with reduced nutrient levels and improved aquatic environment for macroinvertebrates. However, at Site 6, where willows remain and dominate the entire riverbed, poor ecological health is evident and results in impacts downstream.

The presence of toxicants and impacts from treated wastewater, including elevated nutrients and faecal contamination are observed across the study region and may be contributing to lowered ecological health at all of these sites. Continued monitoring will provide a better understanding of the longer-term benefits of the SFMP and how other factors influence overall instream improvements.

Acknowledgments

We would like to acknowledge Coliban Water for funding this project, notably Mr David Sheehan and Mr Brett Thomson. We also acknowledge the contributions from Michael Clark, Gina Mondschein, Daniel MacMahon and Kathryn Hassell for assistance in the field and Hung Vu, Rebecca Reid, Ana Miranda, Tanya Paige and James Oliver for assistance with laboratory sample processing.

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Table 2: Mean physical and chemical indicator responses for monitoring years 1 and 2 of the 5-year program at 8 sites along the Campaspe River.

	Willows removed during Study		Willows removed >10yrs		Willows removed <2yrs						No willow removal		Native vegetation			
Site	1		2		3		4		5		6		7		8	
Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Physical Variables																
Willow cover	15%	0%	0%		0%		0%		0%		100%		0%		0%	
Native riparian cover	0%		5%		5%		10%		15%		0%		70%		50%	
Filamentous algal cover	22%	4%	18%	11%	10%	4%	9%	0.8%	31%	3%	4%	3%	44%	24%	10%	0.4%
Macrophyte cover	56%	83%	52%	85%	59%	56%	61%	78%	43%	38%	41%	48%	33%	46%	4%	2%
Dominant species *Myriophyllium* Sp. MY; *Typha* Sp. TY; *Azolla* Sp. A; *Lemna* Sp. L; *Triglochin* sp. TR; *Allisma* Sp. AL; *Nitella* Sp. N; *Nymphaea* Sp. NY	MY, TR, L, A		MY, TY, L, A		MY, TR, NY		MY, TR		MY, L, N		A, L		MY, AL, CR, TR, A, L		TY, TR, A, L	
Water Quality variables																
Temperature (°C)	13.9	15.9	13.5	16.1	14.2	18.4	13.2	18.0	15.5	18.4	13.9	13.0	14.1	14.6	15.8	15.6
pH	7.7	7.8	7.6	8.1	7.7	7.7	7.8	7.8	7.6	7.2	8.0	7.3	8.2	7.4	7.7	7.3
Electrical conductivity (µS/cm)	400	391	384	395	460	446	434	425	412	431	431	452	492	495	591	581
Turbidity (NTU)	7.8	8.8	6.3	14.3	5.0	9.0	4.7	9.7	9.9	9.1	10.1	9.0	6.4	7.9	7.7	8.7
Dissolved Oxygen (%)	60.1	79.0	55.5	85.5	85.3	86.1	87.0	86.6	71.8	78.9	66.1	56.3	79.8	78.0	82.3	81.2
Total Nitrogen (mg/L)	0.66	1.32	0.66	1.08	0.83	0.97	0.70	0.87	0.74	0.81	1.02	1.35	1.01	0.96	0.87	0.79
Total Phosphorus (mg/L)	0.21	0.08	0.35	0.09	0.11	0.04	0.11	0.04	0.15	0.07	0.35	0.23	0.40	0.21	0.37	0.08
Orthophosphate (mg/L)	0.04	0.02	0.03	0.02	0.02	0.01	0.02	0.01	0.02	0.02	0.26	0.12	0.25	0.15	0.05	0.06
Stock faecal contamination				P				P				P		P		
Other Factors Influencing River health																
Ecological																
Snail Toxicity[1] (% survival)	78%	96%	88%	94%	90%	94%	95%	88%	100%	94%	60%	68%	88%	98%	98%	86%
Algal Toxicity[2] (% inhibition)	42%	26%	39%	4%	25%	12%	18%	33%	33%	37%	- 48%	- 180%	7%	-13%	16%	14%

Water and Sediment Quality																
Heavy Metals	na	Ni	na	Ni	Ni	Ni	Ni	Ni	Ni	Ni	Ni	Ni	Ni, Hg	Ni, Hg	Ni	Ni
Hydrocarbons[3]	na	y	na	y	Y	y	y	y	y	y		y	y	y	y	y
Pesticides Benzotriazole 1; Imidacloprid 2; Triclopyr 3, 2,4-D 4; Simazine 5; Carbaryl 6; MCPA 7; Diuron 8; Atrazine 9	1,2,3	1,3	1,2,3	1,3	1,2,3	1,3,4	1,3,5,6	1,3,4	1,4,5,7,8	1,3,4	1,2,3,6,8	1,3	1,2,3,7,8	1,3	1,2,3,5,6,8,9	1
PPCPs Carbamazepine = 1; Cholesteral = 2; Venlafaxine = 3		1		1		1				2		1, 2	3	1		1
Human faecal contamination (P = present)				P				P		P	P	P		P		

[1] Impact to survival considered significant if <80%

[2] Positive values indicate growth inhibition; 0-20% indicate minimal impact, 20-50% moderate impact and >50% large impact. Negative values indicate increases in algal biomass.

[3] Presence of hydrocarbons in sediments exceeding guideline value of 280 mg/Kg

Table 3: Mean ecological Indicator responses for monitoring years 1 and 2 of the 5-year program at 8 sites along the Campaspe River.

	Willows removed during Year 2		Willows removed >10yrs		Willows removed <2yrs						No willow removal		Native vegetation			
Site	1		2		3		4		5		6		7		8	
Year	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Macroinvertebrates																
SIGNAL	3	3.17	3.4	3.8	4	3.73	3.5	3.77	3.1	3.38	2.9	3.31	3.6	3.23	3.6	4.8
# Families	20	19	20	15	20	27	24	24	15	23	10	16	16	14	19	10
# ETP families	2	2	3	3	6	5	6	5	2	4	1	1	3	1	5	3
Benthic algae																
Chlorophyll a (mg/m^2)	0.011	0.005	0.0006	0.006	0.003	0.005	0.005	0.011	0.002	0.013	0.0008	0.003	0.002	0.010	0.003	0.004
Ash Free Dry Mass (mg/m^2)	179	184	123	93	135	120	274	280	91	302	51	61	138	156	102	79