



## Bioassessment of Dry Season Water Quality in the Ping River Around Chiang Mai City, Thailand

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### ABSTRACT

A longitudinal transect along the Ping River around Chiang Mai city was made during the dry season of 2010 to assess the extent and location of human impacts on water quality. The grab samples showed water quality within the urban area was poorer than upstream. However, physico chemical analyses did not differentiate levels of human disturbance in weir affected by the urban development.

Bioassessment using benthic diatoms and littoral macroinvertebrates did differentiate sites within the city and showed the lower Chonlakhon Pinij weir pool was the most disturbed site. Regional biotic indices for macroinvertebrates ((BMWP<sup>THAI</sup>) and diatoms (Mekong Disturbance Index) were more reliable and discriminating than local (Ping River) the indices.

Overall, the grab sample data showed dry season water quality in the upper (Tha Wang Tan) weir pool within the Chiang Mai city has improved over the past twenty years. But the health of the Ping River downstream of the Mae Kha discharge likely deteriorated over the same period. Future water pollution control efforts around Chiang Mai should consider the impact of the Mae Kha canal on the Ping river.

**Keywords:** bioassessment, benthic diatom, littoral macroinvertebrate, human impact, Ping river

### 1. INTRODUCTION

Agriculture, industry, urban domestic consumption and aquaculture are all increasing the demand for the water resources of the Upper Ping basin in

northern Thailand (Lebel et al. 2009). The potential for over - exploitation of limited aquatic resources is rising along with the demand. We humans need to better

manage our “use” of aquatic systems, to avoid damaging or even completely losing the ‘services’ they provide. As human impacts on river systems increase, so assessments of the biological condition of rivers are becoming more important as tools for managing sustainable (and unsustainable) uses (Jørgensen et al. 2010).

The biological condition of any water body is dependent on the physico-chemical quality of the water and the quality of the available habitats. Thailand’s Pollution Control Department (PCD) has collected physico-chemical data from the Ping River for many years as part of its nationwide survey of river water quality (PCD unpublished). Shorter term physico-chemical data sets have been reported (e.g. Leelahakriengkrai and Peerapornpisal (2010) and Traichaiyaporn and Chitmanat (2008)). However, bio-monitoring techniques can measure important biological components of the aquatic ecosystem directly, at lower cost, lower frequency and with less dependence on sophisticated equipment, than are needed for physico-chemical monitoring. For these reasons, in-stream bio-monitoring has become an established and integral component of watershed-based water quality management programs as complementary method of physico-chemical monitoring in many countries.

The response of aquatic communities over time can be used to evaluate environmental changes (Rosenberg and Resh 1993). Bioassessment is a technique to assess the impact of past and current water quality/pollution events from measures of the organisms present (bio-monitoring). However, pollution tolerance values for taxa used in biotic indices are often region specific. Therefore, when indices are transferred between regions they need to be modified to suit the local conditions (Resh 2007). Biotic indices have been developed specifically for the Ping

River Basin (e.g. Kunpradid (2005) using benthic diatoms; and Silalom (2008) using littoral macroinvertebrates. These indices have subsequently been used to assess the biological condition and river health of locations in the Ping River (e.g. Leelahakriengkrai and Peerapornpisal 2010; Silalom et al. 2010).

Regional and more broadly based indices which could also be suitable for bioassessment of health of the Ping River include MRC (2010) (diatoms and littoral macroinvertebrates); Kelly and Whitton (1995) (Diatoms); and Mustow (2002) (littoral macroinvertebrates). Relevant regional applications using these indices have been reported by Moonsyn et al. (2009) and MRC (2008). An important aspect of this study was review the suitability of these local and regional bioassessment indices for identifying and differentiating the impacts of human disturbance in the Ping River around Chiang Mai city.

This paper reports the results of a pilot investigation, which was part of a larger study to assess the impact of human activities on the health and productivity of cage reared fish. The aim of the pilot study was to identify suitable ‘control’ and ‘treatment’ sites for use in the fish rearing experiment. In addition we evaluate the effectiveness of the biotic indices and other metrics for application to future studies in rivers of the region. Finally we comment on some important changes in water quality within the Chiang Mai city weir pools over the past 20 years.

## 2. MATERIALS AND METHODS

### 2.1 Site Description and Physical Conditions

The historic city of Chiang Mai was founded on the banks of the Ping River in 1296 and the site has been continuously occupied ever since. In 2010, more than 200,000 people were living in the urban area

of Chiang Mai City and the population of Chiang Mai Province exceeded 1.6 million (MOI 2010).

## 2.2 The Catchment of The Upper Ping River

The climate of the Upper Ping Valley in Northern Thailand is monsoonal and about 80% of the annual rainfall occurs from June to October. The dry season can last from November to late April. The area of the Ping River basin above Chiang Mai exceeds 6,400 km<sup>2</sup>. About 80% of the catchment is native forest, 16% is agricultural land and 4% urban landuse (Sriwongsitanon and Taesombat 2011). The landuse in this watershed is changing and human activities like flow modification, riparian zone degradation and increased loadings of suspended sediment, agrochemicals, nutrients and toxic pollutants are increasing the disturbance pressure on the river ecosystem. Within the city proper, the river has been dammed to form the Tha Wang Tan and the Chonlakhlan Pinij weir pools (hereinafter abbreviated to Wang Tan and Pinij respectively).

## 2.3 Surveys of River Health

Potential sites for a fish culture trial were evaluated initially by a grab sample survey of the Ping River, followed by a more targeted investigation of three selected sites. The latter evaluation included bioassessment based on the littoral macroinvertebrate and benthic diatom communities at those three sites.

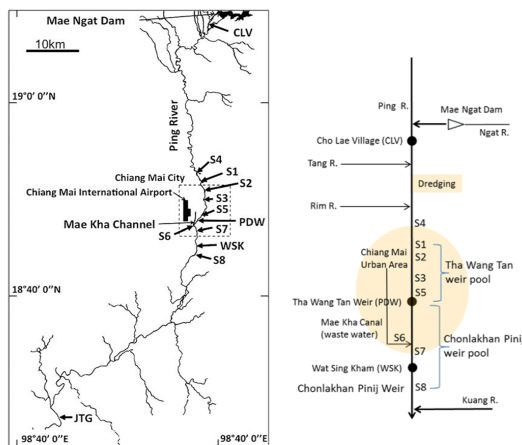
The locations of all monitoring sites along a longitudinal river transect through the city are illustrated in Figure 1 and described in Table 1, along with known human activities likely to cause disturbance to river health.

The initial survey in the dry season (March, 2010) involved *in situ*

measurements and grab sampling for physical, chemical and microbial indicators of pollution, at seven sites in the Ping River plus the Mae Kha canal at the point of discharge to the Ping River.

The first survey was designed with sufficient spatial resolution to detect local sources and cumulative pollution emanating from urban development around Chiang Mai City and to identify the patterns of distribution.

The second survey in the late dry season (April 2010), focused on three locations identified from the results of the first investigation, because resources were limited by the constraints of a pilot study. Nevertheless, because the initial survey had identified differences in physico-chemical aspects of water quality along the transect, we were confident that bioassessment at only three locations would be adequate to identify two sites with sufficient difference



**Figure 1.** Map (A) and schematic diagram (B) of the Ping River around Chiang Mai showing monitoring sites and the extent of the weir pools.

Legend: Biomonitoring sites (solid circles) and physico-chemical grab sample sites (S). The Mae Kha canal conveys untreated waste water plus treated sewage effluent to the Ping River discharge below S6.

**Table 1.** Site descriptions and local human activities contributing to disturbance.

Site <sup>a</sup> Code	Dist. <sup>b</sup> (km)	Co-ords	Impacts	Description
CLV (PI 14)	0	18° 48' 062"N 98° 57' 401"E	Agricultural, rural village, dam discharge	Chor Lae Village (d/s Mae Ngat Dam)
S4	36		Sand dredging	Hwy 121 Bridge on Ping R. u/s Chiang Mai
S1	39		Urban residential (diffuse domestic waste)	Huen Suntaree (Tha Wang Tan WP)
S2 (PI 13)	42		Urban residential (diffuse domestic waste)	Wang Sing Kham Bridge (Wang Tan WP)
S3	45		Urban residential (diffuse domestic waste)	Hwy 11 (Wang Tan WP)
S5 (PI 12)	47		Urban residential (diffuse domestic waste)	Kawila Park (Wang Tan WP)
PDW	47.5	18° 45' 403"N	Urban residential (diffuse domestic waste)	Pa Daed Bridge (in Wang Tan WP)
S6	49	98° 59' 542"E	origin of point source waste effluent	Wang Tan weir overflow
S7	51		residential + Point source waste effluent	Klong Mae Kha at discharge to Ping R
WSK	53	18°41' 562"N	residential + Point source waste effluent + fish cages	Bridge Hwy 121 d/s Chiang Mai city (Piniij WP)
S8	55	98° 59' 221"E	semi-rural	Wat Sing Kham (Piniij WP)
JTG (PI 11)	122		semi-rural	Wat Pa Due (d/s Piniij WP)
				Nong Pla Sawai Bridge, Jom Thong

a = site codes (see Figure 1), codes in brackets (PI XX) denote the code for a site shared with the Pollution Control Department (e.g. CLV = PI 14)

b = distance in river kilometres downstream from the Chor Lae Village (CLV)

in river health condition, to provide a basis for the fish culture experiment.

The assessment involved an initial visual inspection followed by the same water quality sampling as in the screening survey, plus biomonitoring to assess the level of human disturbance.

#### 2.4 Bioassessment Site Descriptions

The most upstream bioassessment site was just below the confluence of the Nam Ngat and Ping Rivers at Chor Lae village (site code CLV). This site was expected to be least affected by human activities.

The second site was near the geographical centre of Chiang Mai city, immediately downstream of the Wang Tan weir (site code PDW). This site was expected to be representative of the river health in the Wang Tan weir pool, which receives drainage and diffuse runoff from the northern suburbs of Chiang Mai city including some of the oldest sections of the city.

The third site and furthest downstream was near the end of the Piniij weir pool (site code WSK). This weir pool receives diffuse drainage from the central and

southern suburbs of Chiang Mai city, combined with a significant direct discharge of treated municipal sewage effluent routed through the Mae Kha canal.

Both urban weir pool sites were expected to show signs of human disturbance and reduced river health compared to the upstream site (CLV).

## 2.5 Physico-chemical and Microbiological Methods

All physical measurements (dissolved oxygen (DO), turbidity, conductivity, pH, and temperature) were made *in situ*, either from a boat or from jetty structures that projected into the main stream. The measurements of ammoniacal-N and thermo tolerant coliforms were from grab samples, which were collected sub surface, stored on ice and transported to the Advance Algal Research Laboratory at Chiang Mai University, (AARL, CMU) where analysis was commenced within 24 hours.

In the laboratory the determinations of ammoniacal N were based on methods from APHA (2005). Thermotolerant coliform levels were determined by the MPN method (APHA 1998).

Measurements of ammoniacal nitrogen, thermotolerant coliforms and turbidity, which were made by the Pollution Control Department of Thailand (PCD), are also presented for four sites within the survey transect (See Figure 1 and Table 1 for site locations). The PCD monitored the sites at least once during the wet season and the dry season each year since 1991, as part of a nationwide water quality monitoring program.

## 2.6 Biomonitoring Methods

Although the purpose of the survey was to identify suitable locations for a fish culture experiment, we did not monitor the health of wild fish populations. This was because free living fish are mobile, so

the health of fish captured at a particular site, may not be representative of the river health at that location. Secondly, wild fish are difficult to sample quickly and effectively and finally fish abundance and species diversity was unlikely to be comparable inside and outside the urban area because of another factor, differences in fishing pressure on the local stocks.

Therefore we selected benthic organisms as indicators of the river health. The littoral macroinvertebrate fauna and benthic diatoms are relatively immobile organisms, so bioassessments based on these taxa represented the river health condition at specific locations, which would be analogous to the exposure of fish in cage culture.

## 2.7 Benthic Diatoms

Benthic diatoms were sampled using the methodology described in MRC (2010). A variation to the method was to combine five sub-samples into a single composite sample (50 cm<sup>2</sup>), and to prepare five of these composite samples at each site.

Diatoms were identified from taxonomic references cited in (Leelahakriengkrai and Peerapornpisal 2010). Where identification to a described species was impossible, the presumptive species was designated by number (e.g. *Pinnularia* sp. 1) were identified from the Mekong River Commission (MRC) reserve collection held at the AARL Lab, CMU.

## 2.8 Macroinvertebrates

Littoral macroinvertebrates were collected at each site using a rectangular frame net (30×20 cm) with 500 μm mesh (UNE-EN 1994); (Leunda et al. 2009). Kick sampling was used at CLV and PDW and sweep sampling was used at WSK to accord with the substrate and the site condition. 125 kick samples were collected at CLV and PDW (representing 7.5 m<sup>2</sup> of substrate) and 125 sweep samples were

collected at WSK (representing 40 m<sup>2</sup> of substrate).

All subsamples collected at the site were combined into a single sample and preserved in 70% ethanol, before sorting and identification in the laboratory (Arimoro and Ikomi 2009). The littoral macroinvertebrates were identified to genus using local taxonomic keys (Sangpradub and Boonsong 2006) except for the Odonatan, Coleopteran and some Dipteran specimens, which were identified to family. Abundance scores for the littoral macroinvertebrates were reported per 3 m<sup>2</sup> of substrate surface, to enable a direct comparison with guidelines established from the Mekong Basin (MRC 2010).

## 2.9 Metrics used for Bioassessment

The richness (the number of taxa identified in each sample) and abundance (the number of individuals per sample) were calculated for all diatom and macroinvertebrate samples. The guideline values for benchmarking river health were drawn from studies conducted in the Mekong Basin (MRC 2008, MRC 2010). A difference in the standard sample size between this study and that used by MRC (2010) precluded the application of the MRC Guideline levels to the richness metrics for macroinvertebrates and diatoms.

Five other biotic indices were used. These indices were specifically designed to assess level of disturbance from the tolerance of the organisms to different types of pollution. Most of the biotic indices were developed in the region so they were expected to be suitable for assessing the water quality of the Ping River (see Table 2 for details). Unfortunately we were unable to use the Mekong Disturbance Index for macroinvertebrates (MRC 2010), which is a new regional index comparable to the MDI for diatoms, as we lacked the MDI tolerance data needed to

analyse the biomonitoring results.

The disturbance indices differed in: the taxonomic level at which a tolerance score was assigned (e.g. macroinvertebrate indices assigned at the family, whereas diatom indices scored by genus); the type of pollution tolerance (nutrients or organic pollution); and in the availability of tolerance scores for the taxa recorded (taxa without assigned tolerance scores for an index were ignored in calculating that index result).

All the metrics listed in Table 2 were used to estimate site condition. The biotic indices use an Average Tolerance Score Per Taxon (ATSPT), which is the average of the tolerances of all taxa recorded in a sample (for which tolerances are assigned). The ATSPT scores were weighted for organism abundance. Although all indices use the range 0-10, they are not inter-comparable for several reasons. Firstly, indices can adopt different conventions in assigning a tolerance score. The MDI, PBI and PNI assign low tolerance scores to taxa that are sensitive to stress and high scores to pollution tolerant taxa which survive at stressed sites. Consequently, high ATSPT scores for these indices indicate harm. The BMWP<sup>THAI</sup> index reverses this convention.

Secondly and more importantly, each index could not always assign a tolerance score to all taxa recorded at each site and if assigned, taxon tolerance scores were not necessarily the same between indices.

## 2.10 Diatom Biotic Indices of Disturbance

Three diatom biotic indices were used, the Mekong Disturbance Index (MDI), the Ping-Nan Index (PNI) and the percentage of Organic Pollution tolerant taxa (OP%). The MDI is a regional index established from surveys of benthic diatoms in rivers throughout the Mekong Basin. The index integrates a number of disturbance effects that can affect

**Table 2.** Bioassessment indices for assessing level of human disturbance.

Index	Indicator Organism	Impacts detected	No. Reference sites <sup>a</sup>	Index source River basin	Reference
BMWP <sup>THAI</sup> <sup>b</sup>	Macroinvert.	eutrophication + organic polln.	Unknown (limited)	Ping (modified)	Mustow (2002)
Ping Basin	Macroinvert.	organic pollution	Nil	British Ping	Silalom (2010)
Mekong Disturbance	Diatom	human disturbance	14	Mekong	MRC (2010)
Ping Nan	Diatom	Eutrophication	2	Ping + Nan	Kunpradid (2005)
OP%	Diatom	Eutrophication + organic polln.	Nil	Britain	(Kelly and Whitton 1995)

a - Reference sites represent unspoiled or least polluted condition. The number of reference sites is reported as a number (in brackets). These were designated in developing some indices (e.g. MDI (MRC 2010)) but were also derived for this review (e.g. for PNI the two furthest upstream sites were designated as reference sites).

b - British Monitoring Working Party (BMWP) index for macroinvertebrates (Clews and Ormerod 2009).

c - MDI (Mekong Disturbance Index) is based on a site disturbance score which includes a subjective assessment of the site disturbance from a wide variety of potential human impacts.

benthic diatom growth (e.g. flow condition, water transparency and nutrient level) plus a site disturbance score (MRC 2010).

The Ping Nan Index is a local index based on surveys of benthic diatom assemblages in the Ping and Nan Rivers in Thailand. This index determines the trophic status of a site based on the nutrient tolerance of the benthic diatom assemblage. The range of the PNI was 0-10 and trophic state increases towards 10.

The OP% index was developed in Britain, specifically to discriminate between eutrophication due to Sewage Treatment Plant (STP) effluent (with high organic load) and eutrophication due to inorganic nutrients. The OP% index classifies each site according to the abundance of organic pollution tolerant diatoms as a percentage of the entire assemblage (Kelly and Whitton 1995).

### 2.11 Macroinvertebrate Biotic Indices of disturbance

Bioassessment indices designed to assess the level of human disturbance in a river

are based on the tolerance of macroinvertebrate taxa (in this case at the family level) to various pollutants including organic compounds and inorganic nutrients. One limitation to the interpretation of biomonitoring results is the requirement for robust biotic indices which are sensitive to local conditions, because of the potential for latitudinal and regional differences in representative fauna even at the family level. These are usually based on local data, so we selected two indices (BMWP<sup>THAI</sup> Index (Mustow 2002) and the Ping Basin Index (PBI) (Silalom 2008; Silalom et al. 2010) which had both had been developed from surveys in the Upper Ping Basin. The BMWP<sup>THAI</sup> index has a more extensive regional basis, as it was adapted from a British model.

### 2.11 Statistical Analyses

The Pollution Control Department of Thailand (PCD) has monitored the physico/chemical quality of the Ping River water since 1992 at three sites on our transect (unpublished). Two PCD sites matched our bioassessment locations (Site

CLV = PCD site PI 14; and PDW = PCD site PI 12). A third PCD site (PI 13) is also located within the Wang Tan weir pool upstream of PDW.

The existing PCD data provided an opportunity to review changes in water quality over time. All data were separated into two seasonal categories (Dry and Other) by sample date. The PCD monitoring design is to sample at least twice annually to record both wet and the dry season runoff.

All data were analysed for seasonal differences within each site and for spatial /seasonal differences between the two sites by t-test of grouped means using SPSS statistical software. The thermotolerant coliform (ThC) data were log transformed prior to analysis.

### 3. RESULTS

#### 3.1 Hydrology

Northern Thailand has a monsoonal climate, which produces a unimodal flow pattern in the Ping River with the peak in July-August each year. Our study was conducted during the low flow period, which extends from March to May. During the period of the study, daily flows over the Tha Wang Tan weir were consistently very low. The range, between 1.8 and 3.5 m<sup>3</sup>/s (RID 2012), was less than half of the historical mean annual minimum daily flow of 8 m<sup>3</sup>/s (RID 2000).

The Mae Kha canal has drained waste water from Chiang Mai city to the Ping River since ancient times. More recently, treated sewage effluent has also been routed to this canal (see Figure 1b). On 10<sup>th</sup> March 2010, the Mae Kha discharge to the Ping River was estimated as 0.7 m<sup>3</sup>/s, from mass balance of electrical conductivity (EC) of canal water (at S6) and river water above and below the discharge point (at S5 and S7) (See Figure 1b for site locations and Table 3 for data).

The maximal rate of discharge from

the sewage treatment plant (STP) was 0.55 m<sup>3</sup>/s. Therefore the untreated urban drainage rate would have been 0.15 m<sup>3</sup>/s or more. That ratio of STP effluent to natural drainage was quite plausible during the late dry season.

#### 3.2 Spatial and Temporal Trends in Water Quality Indicators

The surveys of water quality indicators of human impact generally showed a spatial gradient with low impacts at rural sites upstream of the city, increasing within the urban area and downstream (Table 3).

#### 3.3 Indicators of Faecal Contamination

The concentration of thermotolerant coliforms (ThC) is a widely used indicator of faecal contamination. Although distribution of ThC along the survey transects was patchy, the lowest ThC levels in each survey occurred at the rural sites upstream of the city. There were hotspots (sites with ThC > 1,000 cfu/100mL) in both weir pools, with lower levels (100-200 cfu/100mL) at adjacent sites (Table 3).

Statistical analysis of the ThC dataset collected by the Pollution Control Department of Thailand (PCD) between 1991-2010 showed seasonal and spatial differences were significant. The mean ThC level at the rural site (=CLV) was significantly lower ( $p=0.085$ ) in the dry season compared to "other" times<sup>1</sup>. Moreover, the mean ThC level in the dry season at CLV was significantly less ( $p=0.007$ ) than at PDW (Table 4).

Although there was no significant seasonal difference in ThC levels at the urban weir pool site (=PDW), when the ThC data collected at both PCD sites in the Wang Tan weir pool was pooled and split into two periods, before and after 1998, it was clear that ThC levels have fallen since 1998 in both the dry and 'other' seasonal groups (Figure 2). The decline in the dry season levels was more marked and

**Table 3.** Water quality in the Ping River around the city of Chiang Mai in dry season 2010.

Weir pool	Site Code	Turb. (NTU)	EC ( $\mu\text{S}/\text{cm}$ )	Ammoniacal N (mg/L)	Unionised Ammonia (mg/L) <sup>a</sup>	Thermo-coli. (cfu/100mL)	Diss. O <sub>2</sub> (% sat)	Date (dd/mm/yy)
Tha Wang Tan	CLV	1	131	0.10	0	99	87	7-Apr-10
	S4	66	190	0.37	0.01	134	62	10-Mar-10
	S1	36	189	0.44	0.01	406	52	10-Mar-10
	S2	34	185	0.53	0.01	175	51	10-Mar-10
	S3	38	189	0.45	0.01	186	45	10-Mar-10
	S5	34	188	0.48	0.01	1,100	59	10-Mar-10
	PDW	28	184	0.24	0.01	99	78	7-Apr-10
Penij	S7	32	192	0.59	0.01	311	56	10-Mar-10
	WSK	18	189	0.28	0.01	1,012	76	7-Apr-10
	S8	51	191	0.52	0.02	711	80	10-Mar-10
Mae Kha <sup>b</sup>	S6	14	360	17	0.27	>2,400	23	10-Mar-10
Detection Limit		1-100		0.01		3-2,400		

a - Unionised ammonia is the ammonia fraction that is toxic to aquatic animals. The USEPA (2009) recommends a maximum level for chronic exposure of 0.27mg/L.

b - Mae Kha was the discharge from the Mae Kha canal at the outfall into the Ping River. Site locations are described in Table 1. All results are arithmetic mean of duplicate samples (coliform bacteria results are geometric means).

Coefficient of Variance for each water quality parameter is shown in Appendix 2.

when the period since 1998 was considered separately, there was a significant seasonal difference, with significantly lower ThC levels in the dry season compared to the 'other' (wetter) group ( $p=0.04$ ; Mann Whitney U test).

### 3.4 Turbidity

The rural site (CLV) had the lowest turbidity in the system, although the maximum turbidity was recorded at the site immediately downstream (S4). The turbidity gradually decreased downstream of S4 (Table 3). Moreover historical data clearly showed this spatial distribution has been persistent, with the mean dry season turbidity at CLV highly significantly lower ( $p=0.000$ ) than at PDW (see also Figure 3).

The historical data also showed dry season turbidity was significantly lower than other seasons at both the urban and the rural site ( $p=0.006$  and  $p=0.012$  respectively; see Table 4).

### 3.5 Unionised Ammonia

Ammoniacal nitrogen (Amm-N) is often used as an indicator of organic pollution. In the Ping River surveys in 2010, Amm-N concentrations were lowest (0.25 mg/L) at the upstream rural site (CLV) increasing to a maximum of 0.6 mg/L in the Ping River within the urban area and 17mg/L in the Mae Kha canal. There were no significant seasonal or spatial variations in the levels of Amm-N evident in the historical time series (Table 4).

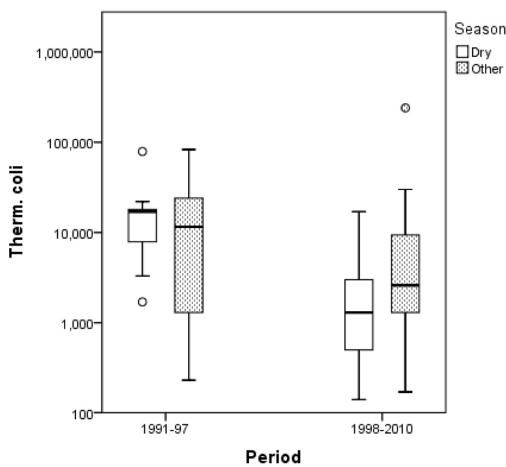
The level of unionised ammonia is more relevant than Amm-N as a stress indicator, because it can be toxic to aquatic animals. The level of unionised ammonia is dependent on pH and temperature. The concentrations calculated from the survey site data were well below the USEPA guideline for chronic exposure at all river sites. Even the polluted Mae Kha canal water met the guideline level of 0.27mg/L of unionised ammonia (Table 3).

**Table 4.** Summary statistics of some indicators of human impact, in the Ping River above and within Chiang Mai city (1991-2010).

Parameter	Site Code	Mean* (Dry)	Mean* (Other)	S.E. (Dry)	S.E. (Other)	Significant seasonal difference?	Signif. spatial difference (Dry)?	Signif. spatial difference (Other)?
Amm-N (mg/L)	PDW CLV	0.18 0.12	0.15 0.12	.053 .048	0.025 0.019	No No	No No	No No
Turbidity (NTU)	PDW CLV	43 15	121 98	5.5 1.9	23 25	p=0.006 p=0.012	p=0.000	No
ThC* (cfu/100mL)	PDW CLV	3,509 835	4,633 2,112	.136 .172	0.145 0.151	No p=0.085	p=0.007	No

Mean\* = ThC (Thermotolerant coliforms) statistics were calculated using log transformed data. S.E.(Dry) = Standard error for dry season samples

PCD (Pollution Control Department Thailand) provided data to make this table.



**Figure 2.** Seasonal and temporal effects on concentration of thermotolerant coliform (ThC) in the Tha Wang Tan weir pool, Chiang Mai city.

Legend: Box plots of records from two PCD sites (PI 13 and PI 12) in the Tha Wang Tan weir pool (PI 12 = PDW). The box represents the 25 to 75 %-ile range. Whiskers represent the 95% confidence interval. Circles are outliers. Original time series plot was shown in Appendix 1.

### 3.6 Bioassessments of Human Disturbance

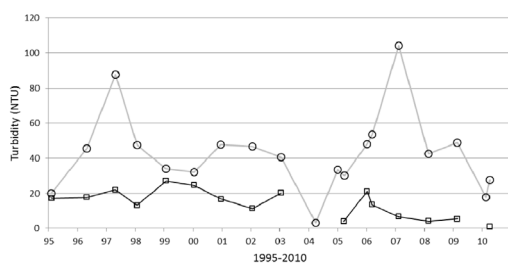
The initial survey by grab sampling, in March 2010, identified that levels of environmental stressors linked to human disturbance were lower upstream of Chiang Mai city than in the weir pools within the city precinct.

However, the survey was not adequate to distinguish differences in biological condition and river health of the city weir pools. Therefore a biomonitoring study was added to the second survey in April 2010, to assess the biological condition of the weir pools compared to an upstream site.

Complete results from those surveys, as taxonomic lists of benthic diatoms and littoral macroinvertebrate, are provided as an Online Resource (ESM 1). This paper evaluates those ‘raw’ data using bioassessment techniques.

### 3.7 Benthic Diatom Metrics of Disturbance

The relative level of disturbance along transect was estimated from site scores, whilst the ‘river health’ was assessed against benchmark guidelines from the literature. The benthic diatom based Mekong



**Figure 3.** Dry season turbidity levels in the Ping River around Chiang Mai city  
 Legend: Dry season turbidity at the upstream site (CLV open circles) and in the Wang Tan weir pool at Padaed Bridge (PDW) open squares).

Disturbance Index (MDI) showed disturbance increased with distance downstream. The MDI classified the rural site at CLV as “undisturbed”. Whilst both urban sites showed ‘significant likelihood of human disturbance’, the most downstream site (WSK) ranked most disturbed (i.e. highest MDI score, Table 5).

The Organic Pollution (OP%) biotic index is designed to detect pollution by organic compounds. This index classified WSK as ‘contaminated’) and clearly differentiated that site from CLV and PDW, which were both classified as ‘clean’ (i.e. less than 20% abundance of taxa tolerant to organic pollution; Table 5).

There were a few abundant diatom taxa at each site, which were rare or absent elsewhere. These taxa are listed in Table 6. The dominant taxa at WSK were pollution tolerant, which was the basis for the OP% index classification of “polluted” and the differentiation of WSK from the other sites.

The abundance metric clearly differentiated between the two weir pools. The least disturbed (highest abundance) was at PDW and the most disturbed (lowest abundance) was at WSK, which the MDI guideline for river health classified as having a high probability of human

disturbance (Table 5).

The diatom taxonomic richness metric was least effective as it did not clearly differentiate the sites (e.g. CLV = WSK; Table 5). The MRC river health guideline values for taxonomic richness were not applicable in this study because of a methodological difference.

Anthropogenic eutrophication can have a significant impact on plant growth in rivers. The typical response by benthic diatoms is increased abundance (e.g. Chl̄telat et al. (1999); Camargo et al. (2005)). The MRC river health guideline based on diatom abundance (MRC 2010) only considered inhibitory growth factors as sources of environmental harm. We modified the guideline to also detect eutrophication impacts by establishing a maximum acceptable cell abundance per sample of  $> 376 \text{ cell/sample}^2$ . However, cell abundances at all three Ping River sites were well below this level, so anthropogenic eutrophication was not likely to be a disturbance factor at these sites.

### 3.8 Littoral Macroinvertebrate Metrics of Disturbance

The levels of disturbance and river health at each site was assessed using four macroinvertebrate metrics. The BMWP<sup>Thai</sup> and the Ping Basin (PBI) indices both detect organic pollution through change in community composition. These assessments are most effective when every taxon sampled is assigned a pollution tolerance score by the index. In this survey, the BMWP<sup>Thai</sup> and the PBI indices assigned tolerance scores to 82% and 78% of recorded taxa, respectively. BMWP<sup>Thai</sup> classified the WSK site as ‘unhealthy’ and it was clearly differentiated from PDW and CLV, which had equivalent disturbance scores and classified borderline ‘healthy’; see Table 7). In contrast to BWMP<sup>Thai</sup> the PBI did not clearly differentiate between

**Table 5.** Assessments of water quality in the Ping River around Chiang Mai City using different benthic diatoms indices.

Index (units)	Index responds to	Indicator of harm	Value at Ping River site			Healthy river Guideline	Usefulness of Index
			CLV	PDW	WSK		
MDI (ATSPT score)	disturbance	High value	30.5	40.2	44.9	<sup>a</sup> < 38.4	Discriminated rural and urban sites
OP% (% of all taxa)	organic compounds	High value	5%	1%	28%	< 20% <sup>b</sup>	Identified organic pollution impact
Ping Nan (ATSPT score)	nutrients	High value	3.6	3.2	3.7	< 3.3 <sup>c</sup>	Ambiguous - Harm at WSK AND also at CLV
Richness (taxa/sample)	disturbance	Low value	10.2	8.2	10.0	N/A	Failed to discriminate between CLV and WSK
Abundance (cell/0.2 cm <sup>2</sup> )	disturbance	Low value	122	190	72	> 136 <sup>d</sup>	Identified organic pollution impact

Values in **bold** indicate a potential for harm as they exceed the guideline for a healthy river.

a - Scores were derived using methods comparable with those used to set the guideline.

b - The percentage abundance of those taxa that tolerate organic pollution

c - Guideline was derived from Kunpradid (2005) based on the 90th percentile at the most upstream (reference) site on the Ping River.

d - The MRC guideline is the 10th percentile from reference sites (i.e. less than 90% of all reference values). A score below the guideline means there is a significant probability of human disturbance and the lower the score, the more harm.

**Table 6.** Pollution tolerance scores of site specific diatom taxa.

Site	Diatom Taxa	Site specificity	MDI <sup>a</sup>	PNI <sup>b</sup>	OP% <sup>c</sup>
CLV	<i>Cymbella affinis</i>	+++	55	n/a	
	<i>Cymbella tumidula</i>	+++	16	n/a	
	<i>Nitzschia clausii</i>	++	57	n/a	X
	<i>Pinnularia mesolepta</i>	++	51	n/a	
PDW	<i>Cyclotella pseudostelligera</i>	+++	21	n/a	
	<i>Achnanthes oblongella</i>	+++	31	n/a	
	<i>Thalassiosira</i> sp. 1	+++	66	n/a	
WSK	<i>Nitzschia frustulum</i>	+++	27	n/a	X
	<i>Nitzschia dissipata</i>	++	35	3	X
	<i>Gomphonema parvulum</i>	++	30	4	X
	<i>Sellaphora pupula</i>	++	43	3	X
	<i>Cyclotella meneghiniana</i>	++	31	n/a	

+++ This taxon was very common at this site and rare/absent elsewhere

++ This taxon was ONLY present at this site

n/a - not rated for pollution tolerance in this index

a - MRC (2010); b - Kunpradid (2005); c - The taxa marked X tolerate organic pollution (Kelly and Whitton 1995)

the sites and the PBI classified both CLV and WSK as borderline ‘healthy’.

The taxonomic richness and abundance metrics both showed a clear trend of increasing disturbance and declining river health downstream along transect. The MRC river health guideline based on

abundance classified WSK as the only “unhealthy” site (Table 7).

#### 4. DISCUSSION

##### 4.1 Grab Sample Indicators of Water Quality

The surveys (10 March and 7 April of

2010) occurred in the late dry season during a period of very low flow, when inputs from the broad catchment were expected to be minimal and point sources within local subcatchments were expected to dominate the water quality at each site.

We propose that the ThC hotspots detected in the Wang Tan weir pool in the dry season were most likely from local catchment sources, whereas remote catchment sources predominate in the wet season. This conclusion was based on; long term records that show ThC levels significantly higher in both city weir pools than at upstream rural sites during the low flow period (late dry season); and significant higher ThC levels at the rural site in the wet season. The historical turbidity data were consistent with the ThC findings, that wet season flows mobilise inputs from catchment wide sources.

The significant fall in dry season ThC levels in the Tha Wang Tan weir pool since 1998, suggests improved management of faecal pollution sources within the local catchment over that period.

A similar assessment of faecal coliform sources to the Piniw weir pool was not possible because; PCD has not made routine ThC measurements downstream of the Mae Kha outfall; and because measurement uncertainty in Mae Kha ThC concentration prevented an accurate assessment of the contribution of ThC from this source<sup>3</sup>.

The high clarity of the Ping River at CLV, upstream of Chiang Mai city, could be attributed to the location of the site, downstream of the 'clear water' discharge from the Mae Ngat Reservoir and immediately upstream of a major gravel dredging operation in the Ping River.

The longitudinal survey indicated that the gravel dredging operation was the main source of turbidity to the city weir pools during low flow period. However, phytoplankton growth would also contribute to turbidity during low flows by replacing sedimenting suspended particles.

Although low water clarity is often regarded as a biological stressor in rivers, relatively un-impacted rivers in the region

**Table 7.** Macroinvertebrate indices of water quality in the Ping River around Chiang Mai.

Index (units)	Response to	Indicator of harm	Value at Ping River Site			Healthy River Guideline	Usefulness of Index
			CLV	PDW	WSK		
BMWD <sup>THAI</sup> (ATSP score) Ping Basin (ATSP score)	Nutrients and organic compounds	Low value	5.9	5.9	4.2	> 6	Clearly differentiated the most polluted site Anomalous - very weak discrimination between the least and most polluted sites
	Organic compounds	High value	3.9	4.2	3.9	< 3.9	
MDI-Richness (taxa/sample)	Biodiversity	Low value	45	27	20	n/a	Differentiated all sites on a gradient of rising pollution
MDI-Abundance <sup>a</sup> (org/sample)	Disturbance	Low value	524	341	8	> 46.7 <sup>b</sup>	Clearly differentiated the most polluted site

Values in **bold** indicate a potential for harm as they exceed the guideline for a healthy river.

a - Abundance data reported as organisms per standard sample (see methods section and MRC, (2010) for the specification of this standard)

b - This guideline is derived from the 10th percentile score for all the MRC reference sites. Scores below the guideline mean there is a significant probability of human disturbance at the site.

n/a - no applicable richness guideline as the study data were not convertible to a 'standard' sample.

(e.g. Mekong basin) can have naturally high turbidity levels (MRC 2010). Therefore regional aquatic biota are likely adapted to the turbidity levels recorded in the Ping River.

#### 4.2 Bioassessment of Disturbance Effectiveness of Various Metrics for Assessing The Health of The Ping River

We monitored two groups of indicator organisms, benthic diatoms and littoral macroinvertebrates, to increase the sensitivity of the assessment by expanding the range of disturbances that can be detected. In addition, we calculated a variety of different metrics for each organism group, to give a more comprehensive assessment of river health, (e.g. MRC 2010).

A summary of results from the most effective metrics for both organism groups (Table 8) showed unequivocally that site WSK in the Pinij weir pool downstream of Chiang Mai city had the highest level of disturbance.

Biotic disturbance indices based on the composition of the macroinvertebrate community (BMWP<sup>THAI</sup>) and the benthic diatom assemblage (MDI) were the most discriminating metrics, as both indices differentiated all three sites and showed a gradient of increasing disturbance from above Chiang Mai city (CLV) to below (WSK).

The OP% index results clearly identified organic pollution as an important stressor for the benthic diatom assemblage at WSK and the Mae Kha canal which conveys treated sewage and untreated urban runoff, was the most likely source of these organic compounds.

#### 4.3 Limitations in Some Metrics

As the level of physico chemical disturbance indicators was clearly different between all three sites, we compared the sensitivity of the local and the regional

biotic indices of disturbance. The locally developed biotic indices based on diatoms (PNI) and macroinvertebrates (PBI) gave anomalous disturbance scores compared to the other metrics. For example, the PNI classified the CLV site as 'polluted' and PBI classified WSK as 'unpolluted'.

One explanation for the anomalous PNI results may be the lack of tolerance scores for the diatom taxa that characterised each site (see Table 6). Only nine of the 28 diatom taxa recorded in this study were assigned tolerance scores in the PNI, whereas the MDI assigned scores to 18 of 28 taxa.

Although the PBI was locally derived, apparently most sites were relatively unpolluted (Silalom et al. 2010). Evidence from this study suggests the PBI is unsuited to assessing river conditions at polluted sites.

#### 4.4 Changes in The Health of The Ping River

A benchmark study of the health of the Upper Ping River in 1990-2, used the BMWP<sup>Thai</sup> index scores to assess the condition of 10 sites along a 110 km transect around Chiang Mai (Mustow 2002). Our study found no change in condition at the CLV site since that time. The disturbance score in 2010 was within the narrow range of scores for dry season samples collected between 1990 and 1992 (Figure 4).

Although sites within the Tha Wang Tan weir pool were monitored in 1990-92, their disturbance scores should not be compared to other sites on the Ping River in 1990-92, or the PDW site in this study, because of methodological differences (the weir pool sites were sampled for benthic macroinvertebrates using a dredge) (Mustow 2002).

The third site assessed in this study (WSK) also lacked a direct match in the 1990-92 survey, but some conclusions can

**Table 8.** Summary of bioassessment of pollution in the Ping River around Chiang Mai.

Bioassessment Group	Metric	Likelihood of pollution		
		CLV	PDW	WSK
Macroinvert	BMWP <sup>THAI</sup>	1	1	0
Macroinvert	Abundance	1	1	0
Diatom	MDI	1	0	0
Diatom	OP%	1	1	0
Diatom	Abundance	0	1	0
Total metric score		4/5	4/5	0/5
River Health Rating <sup>a</sup>		Good	Good	Poor

Site codes are explained in Table 1 and indicators are described in the methods. The PBI and PNI results were excluded as anomalous. The river health was assessed from the site score and a guideline for each metric.

**Legend:** metric score 1 - healthy; 0- likelihood of pollution

a- River Health Classification scores modified from MRC (2010) Table 9.2.

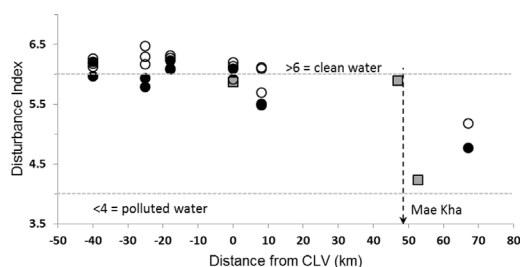
Good - Level of biodiversity slightly reduced from reference site conditions; Species composition has many taxa that are sensitive to pollution; Ecological capacity of the river to support production of fish and other biological products slightly below the range of capacity of reference sites; Some disturbance from human activities.

Poor - Level of biodiversity significantly altered from reference site conditions; Species composition dominated by taxa that are tolerant to pollution; Ecological capacity of the river to support production of fish and other biological products far below the range of capacity of reference sites; Several negative to extensive adverse impacts from human activities.

be drawn from results collected from site P10, which is 14km downstream of WSK (+68 km d/s of CLV in Figure 4). In April 1992 the P10 site recorded the lowest disturbance score for the entire 1990-92 survey of 4.8. The score recorded at WSK in April 2010 was 4.2, which was considerably lower (i.e. more disturbed).

Thus the poor health condition in the Pinij weir pool identified in this study, confirmed the finding of Mustow 2002 that river health in 1992 was worst downstream of Chiang Mai city. The unresolved question is whether the poor river condition at WSK is a long standing phenomenon, due to closer proximity to the Mae Kha discharge, or whether the impact of the Mae Kha has increased since 1992 as a consequence of urban expansion of Chiang Mai city.

An assessment of the impact of the Mae Kha discharge on the Ping River in 1992-93 using a different bio indicator method, found minimal change in the condition of the river reach 500m downstream from the discharge point (Mustow et al., 1997). But the authors



**Figure 4.** Changes in river health condition in the Ping River around Chiang Mai city between 1990 and 2010 derived from on the BWMP<sup>THAI</sup> disturbance index using littoral macroinvertebrates.

Legend: The X-axis shows distance upstream (negative) or downstream of Chor Lae Village (CLV). All data collected at sites monitored in this study (CLV, PDW and WSK) in the late dry season of 2010 is represented as shaded squares. Data from 1990-1992 are presented as circles (solid = dry season and open = other seasons) (calculated from Mustow (2002)). Dotted lines are BWMP<sup>THAI</sup> guideline scores for clean water >6 and moderately polluted water <4. The vertical down arrow shows the discharge point of the Mae Kha canal to the Ping River.

qualified their conclusion with the comment that losses of the biological indicator (chironomid exuvia) through decomposition and/or high seasonal flows could have confounded the result.

Evidence presented in this study shows there has been a significant improvement in the dry season water quality in the Tha Wang Tan weir pool within the urban area of Chiang Mai city, which is likely due to better management of diffuse sources in the local catchment. Future management efforts should also focus on also improving the condition of the Piniw weir pool, as population growth and urban expansion increases pressure on this water resource to sustain multiple uses including aquaculture.

## 5. CONCLUSIONS

We made a grab sample survey using physical, chemical and biological indicators of water quality to identify suitable sites for a fish cage culture growth experiment. The best water quality was upstream of Chiang Mai city, but the grab sample survey indicators did not clearly differentiate the water quality of the two weir pools affected by urban runoff.

Selective application of biotic metrics of disturbance was able to identify the WSK site in the Piniw weir pool below Chiang Mai city, as more disturbed than the Tha Wang Tan weir pool upstream. The OP% biotic index clearly identified organic pollution as an important disturbance factor for the benthic diatom assemblage at the WSK site. The Mae Kha canal was the likely source of that contamination.

A review of historical monitoring data from various sources in the region indicated that dry season contamination of the Tha Wang Tan weir pool is declining. It is recommended that future management efforts should also consider the impacts of the Mae Kha canal on the Ping River.

It is reasonable that the one experimental cage culture site is selected near Chor Lae Village (CLV) as an undisturbed site (healthy environment) in the upstream of Chiang Mai city, the other site is selected near Wat Sing Kham (WSK) in the downstream of Mae Kha canal from Chiang Mai city as a disturbed site (a polluted site) in order to obtain clear results in the assessment of the impact of human activities on the health and productivity of cage reared fish in the next study.

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## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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