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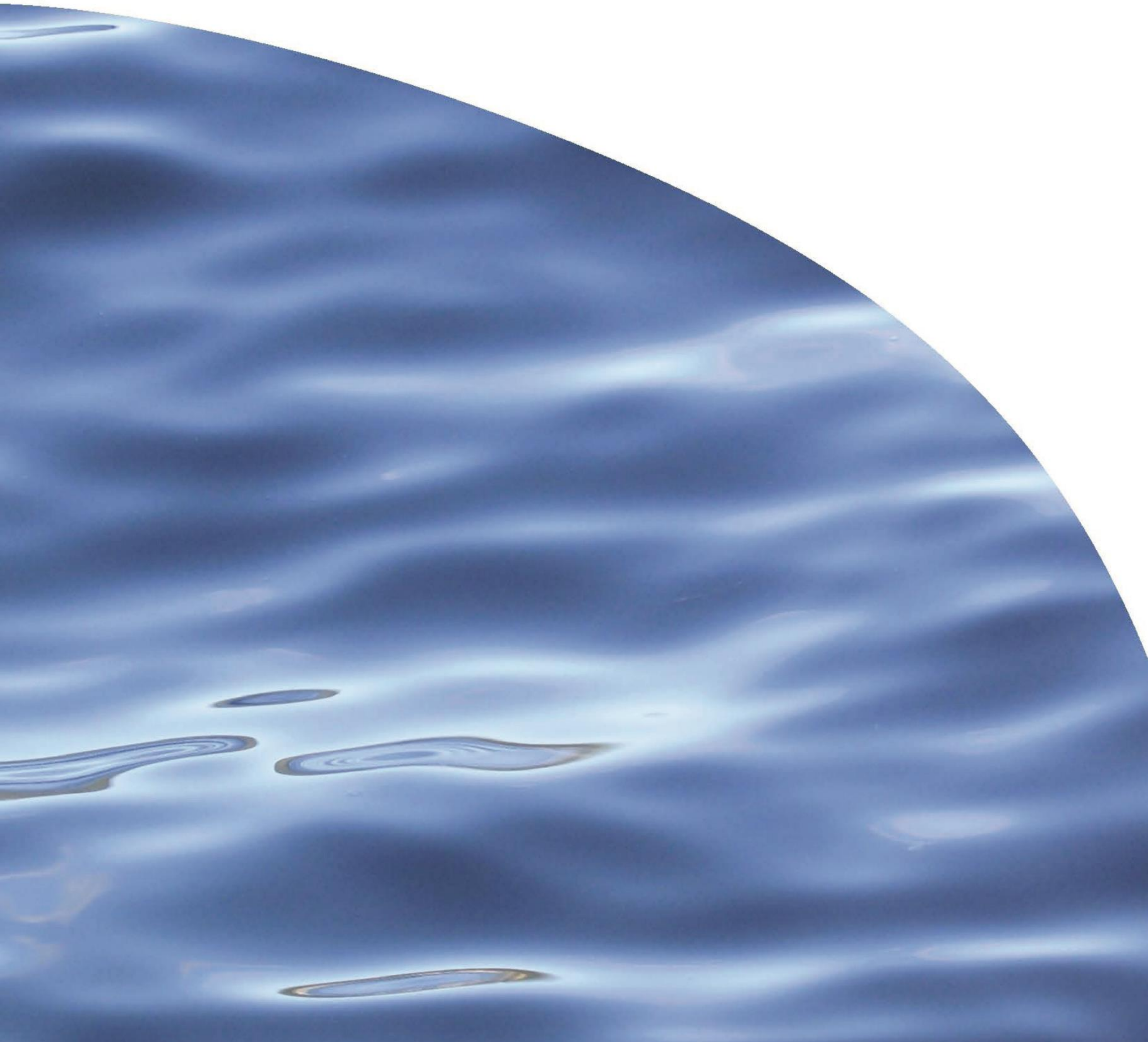
EFFECTS OF THE 2019 DROUGHT ON AQUATIC ECOLOGY IN SELECTED WATERWAYS IN GOLDEN BAY



EFFECTS OF THE 2019 DROUGHT ON AQUATIC ECOLOGY IN SELECTED WATERWAYS IN GOLDEN BAY

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Prepared for Tasman District Council

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EXECUTIVE SUMMARY

Tasman District Council (TDC) commissioned Cawthron to undertake an ecological survey of rivers and streams in the Golden Bay region at the end of a severe drought in the summer of 2019. The drought resulted in record low mean annual 7-day low flows in Golden Bay rivers and streams. The survey was intended to provide TDC with information on the state (health) of waterways under an extreme low flow event, and aid in:

- understanding the drought impacts on these ecosystems and
- setting transparent and equitable water use rules for human communities in the Takaka Freshwater Management Unit.

The water quality, periphyton and invertebrate results presented in this report are arguably typical of what we would expect to see in rivers with a predominance of native forest in the headwaters and under drought conditions. Despite the drought, the periphyton and invertebrate communities were still relatively healthy. However, aquatic communities were likely experiencing stress due to reduction in physical habitat (stream area), and maximum water temperatures and minimum dissolved oxygen concentrations arising from drought conditions, which will not have been captured through spot sampling. Our ecological survey did not include an assessment of invertebrate and fish abundance, nor fish growth. When water quality is good, periphyton will not usually proliferate to nuisance levels and invertebrate diversity will be maintained during low flow conditions. This is the picture revealed by our study of the Golden Bay rivers and streams at the end of the 2019 drought. However, the main hydrological effect is reduced flow, and this translates to reduced wetted area for supporting periphyton and benthic invertebrate production. The reduced wetted area and benthic production have potential adverse consequences for available suitable habitat and food supply for fish. Potential adverse effects on fish include reduced growth rate and abundance, the magnitude of effects increasing with the duration of low flows. Furthermore, our survey represents a single datapoint in time, and for many of the rivers and streams it is the only ecological information on record—thus we have no comparative data at other river flows.

We recommend that:

- TDC collates any fish survey data collected during or within a year after the 2019 drought from Golden Bay rivers and streams and compares species presence/absence and any abundance data available with historical data.
- At least two further water quality and ecological surveys of the study rivers and streams are undertaken at flows around median and 7-day mean annual low flow to provide better environmental context, i.e. find out how the water quality, periphyton and invertebrate communities under drought condition compare to more 'typical' flow conditions.
- Collection of the following water quality and physical data including, 1) continuous DO, 2) continuous temperature, 3) wetted width (and/or area), and 4) flow.

Continuous DO and temperature would be collected at representative sites surveyed in this study (i.e. sites will be grouped (e.g. by river type or stream size), and a selection chosen for DO/temperature meter placement). These data would allow biological data to be placed in better context of some of the major effects of river flow change on ecosystem function and habitat.

The above surveys would provide additional ecological baseline information on the resilience of rivers/streams in the Takaka FMU to low flow stress under current land use practices, helping inform TDC for setting and meeting statutory targets under the National Policy Statement–Freshwater Management to safeguard life-supporting capacity, ecosystem processes, and indigenous species.

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1. INTRODUCTION

The Takaka Freshwater Management Unit (FMU) in the Tasman District Council (TDC) region covers all catchment areas from the Wainui catchment in the east to the Tukurua catchment in the west, comprising all catchments that drain to the Takaka River and the Arthur Marble Aquifer. Currently there are formal policies for water allocation based on a portion of low flow in the Tasman Resource Management Plan for the Takaka FMU and there is unmet demand, with an informal waiting list for additional water allocation. The management of effects of water and land use practices on water quality and quantity is a key driver for freshwater planning in the region. Under the National Policy Statement for Freshwater Management (NPS-FM), TDC has a statutory requirement in the Takaka FMU to safeguard fresh water life-supporting capacity, ecosystem processes, and indigenous species, maintain or improve the overall quality of fresh water and set limits on resource use (e.g. how much water can be taken or how much of a contaminant can be discharged) to meet limits over time and ensure they continue to be met.

In the summer of 2018/19 a severe drought resulted in record low mean annual 7-day low flows in rivers and streams in the Golden Bay region (Figure 1). In response TDC, assisted by the Cawthron Institute, undertook an ecological survey in some Takaka FMU rivers and streams. The survey was intended to provide TDC with information on the state (health) of waterways under an extreme low flow event, and aid in 1) understanding the drought impacts on these ecosystems and 2) setting transparent and equitable water use rules for communities in the Takaka FMU.

The information collected during the survey included site photos, water quality, macroinvertebrate samples, average percent periphyton cover and physical measurements of the wetted width of runs and riffles. The TDC requested to have the ecological data analysed from the perspective of drought impact on ecosystem health. This report provides a basic description of each site, analyses and interpretation of the water quality, periphyton and macroinvertebrate data in relation to relevant aquatic guidelines. A recommendation is also made to repeat the survey on each river or stream on at least two more occasions at higher flows.

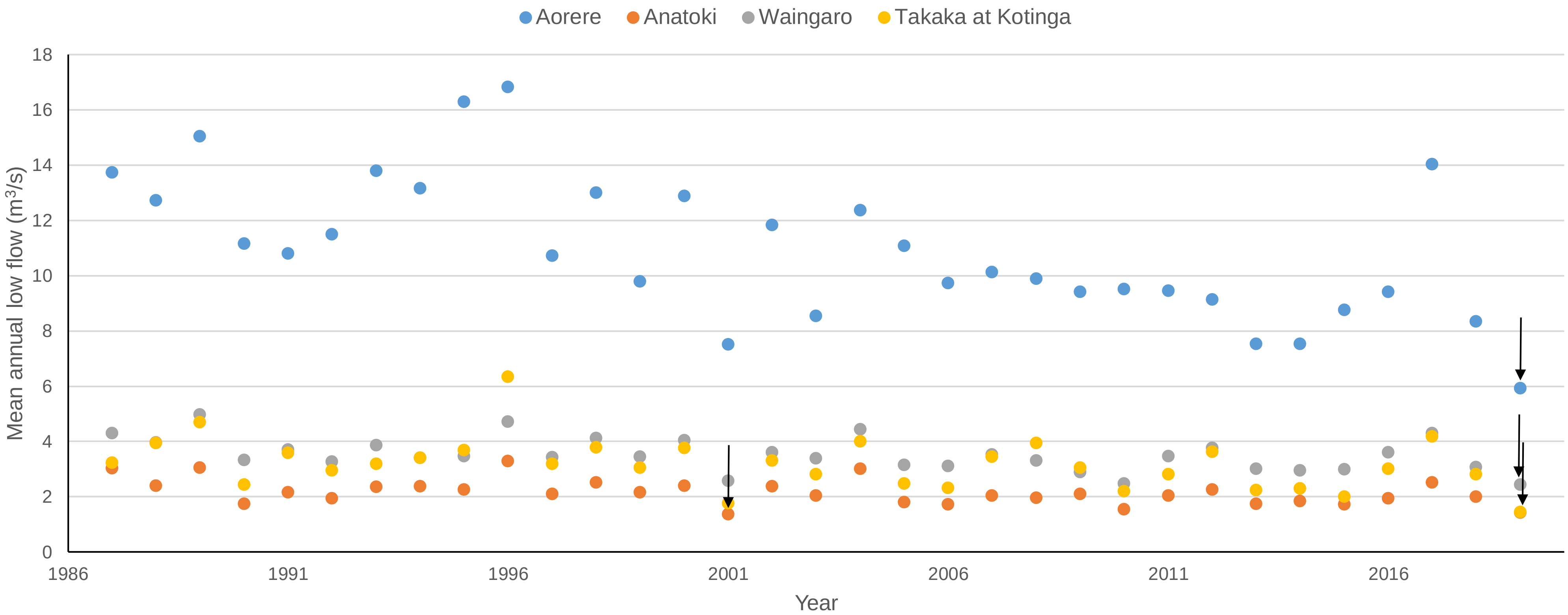

Figure 1. Annual 7-day flow minima for four Golden Bay rivers (Aorere, Anatoki, Waingaro and Takaka at Kotinga) from the summer of 1987 to 2019. Arrows indicate the lowest annual 7-day flow minima on record for each river. After 2001, the second lowest annual 7-day flow minimum for the Anatoki River was recorded in the summer of 2019.

2. SURVEY SITES AND SAMPLING METHODOLOGY

2.1. Sites

Fourteen rivers and streams were selected over the Golden Bay region for the survey (Figure 1, Table 1, Appendix 1). Some of the rivers and streams are monitored monthly as part of TDC’s State of the Environment (SOE) programme (e.g. Kaituna River at Solly's, Aorere River at Le Comte, Takaka River at Kotinga), while others have been rarely sampled, if at all.

Seventeen sites were visited over two days, with the drought breaking as the last site was being sampled. Because of the limited time frame to undertake the work, sites had to be easily accessible from the road. A basic physical description of each river or stream is provided in Table 2, including the size of the catchment and predominant land use. Photos were taken of each site and a selection of these are presented in Appendix 2. Photo montages were also created that show the change in appearance of river reaches, including reduction in wetted width and area, with reduced flows (e.g. between the extreme low flow event and near mean annual low flow (MALF)). The montages and other photos for each site are available on request from the Tasman District Council.

Anatimo Creek was the only waterway sampled at more than one site (Table 1). This creek has an existing water take on it and could be easily accessed immediately upstream and downstream of the water take (forested headwater) and also further downstream where the stream flowed through open pasture. Sampling at these four sites provided the opportunity to evaluate potential drought effects on the stream ecology along a longitudinal gradient.

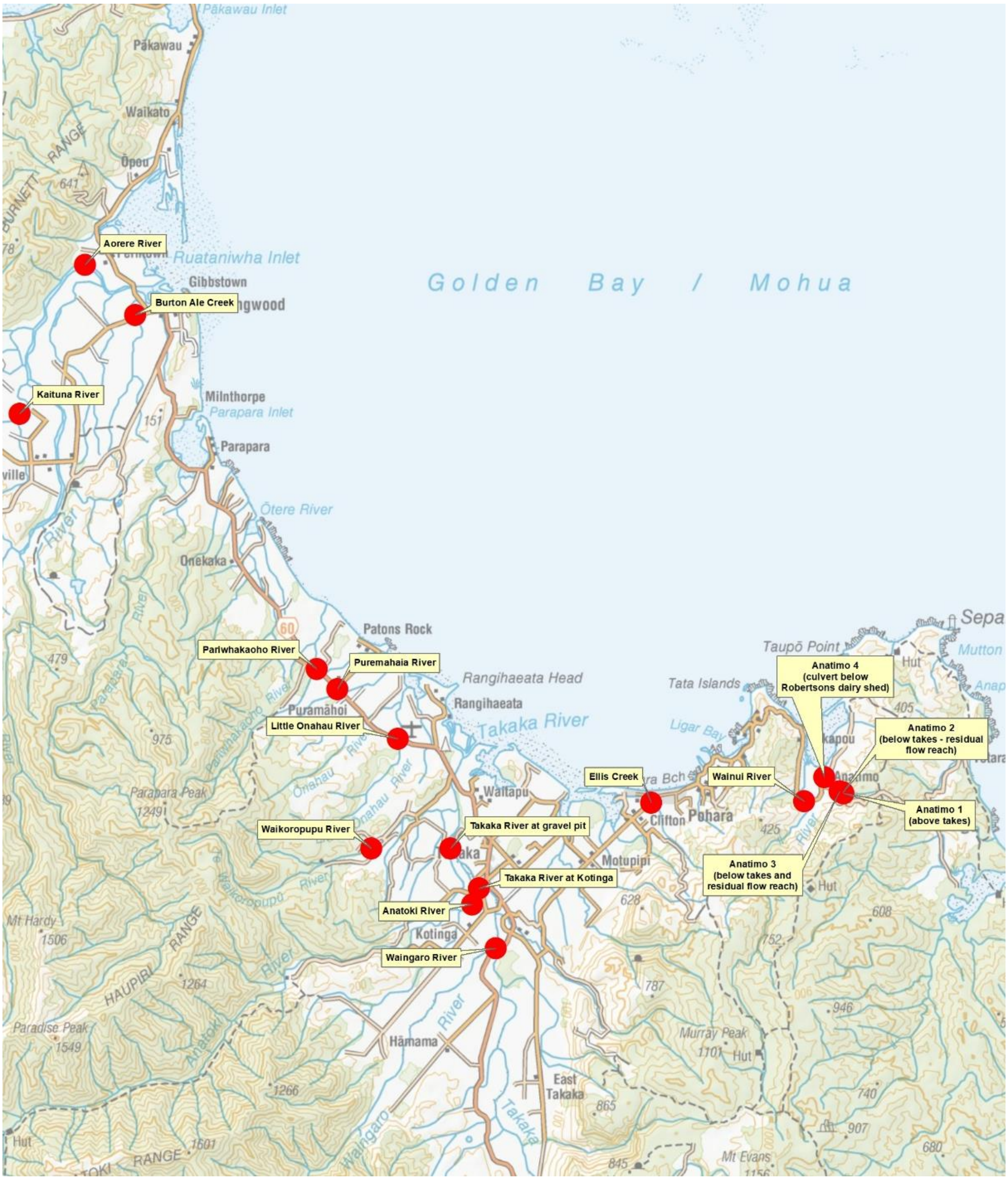

Figure 2. Map showing the location of sites in the Golden Bay region sampled during the drought ecological survey on 6 and 7 March 2019.

Water quality, periphyton and macroinvertebrate samples were collected from all sites during the survey apart from the following exceptions. Water quality measurements were not taken from three of the Anatimo Creek sites, i.e. Anatimo 2-4 (Table 1), the measurement taken at Anatimo 1 being considered representative for the rest of the creek. Periphyton cover was not estimated at Burton Ale Creek as it was densely covered in macrophyte growth with flow practically non-existent. Periphyton assessments were not done in the Little Onahau and Anatoki rivers due to time constraints. Macroinvertebrate samples were not collected from the Aorere River as samples had been recently collected from the site as part of TDC's annual SOE monitoring. Macroinvertebrate samples were not collected from the Little Onahau, and Anatoki rivers due to time constraints.

Table 1. Checklist of water quality, periphyton and macroinvertebrate measurements or samples taken at each site. Grey shading indicate site where macroinvertebrate samples were processed on the stream bank. All other macroinvertebrate samples were processed in the laboratory. Further explanation of sample methodologies is provided in Section 2.2.

Site name	Water quality	Periphyton	Macroinvertebrates
Anatimo Creek: Anatimo 1 (above takes)	✓	✓	✓
Anatimo Creek: Anatimo 2 (above takes) (below takes - residual flow reach)	×	✓	✓
Anatimo Creek: Anatimo 3 (below takes and residual flow reach)	×	✓	✓
Anatimo Creek: Anatimo 4 (culvert below Robertson's dairy shed)	×	✓	✓
Wainui River	✓	✓	✓
Ellis Creek	✓	✓	✓
Waikoropupu River	✓	✓	✓
Pariwhakaoho River	✓	✓	✓
Aorere River	✓	✓	×[1]
Kaituna River at Queen's Farm bridge	✓	✓	✓
Puremahaia River	✓	✓	✓
Little Onahau River	✓	×	×
Takaka River at gravel pit	✓	✓	×
Takaka River at Kotinga	✓	✓	✓
Burton Ale Creek	✓	×	×
Anatoki River	✓	×	×
Waingaro River	✓	✓	✓

[1]However, macroinvertebrate indices calculated from SOE monitoring data collected from the Aorere River (28 February 2019) is presented in sections 5.2 and 5.3 of this report.

Table 2. Physical description of sites—catchment area and land use. Predominant land use was estimated using the River Environment Classification database.

Site name	Catchment area (km^2)	Predominant land use
Anatimo 1 (above takes)	1.2	Native forest
Anatimo 2 (above takes) (below takes - residual flow reach)	1.6	Native forest
Anatimo 3 (below takes and residual flow reach)	1.8	Native forest
Anatimo 4 (culvert below Robertson’s dairy shed)	2.7	Native Forest*
Wainui River	29.0	Native forest
Ellis Creek	2.8	Pasture
Waikoropupu River	19.0	Native forest
Pariwhakaoho River	12.3	Native forest
Aorere River	573.0	Native forest
Kaituna River at Queen’s Farm bridge	79.0	Native forest
Puremahaia River	4.5	Native forest
Little Onahau River	8.6	Shrub
Takaka River at gravel pit	836.0	Native forest
Takaka River at Kotinga	714.0	Native forest
Burton Ale Creek	0.8	Pasture
Anatoki River	130.0	Native forest
Waingaro River	235.0	Native forest

* The upper catchment for this site is native forest, but the site is in a lowland section of the creek that flows through open pasture.

2.2. Sample methods

2.2.1. Water quality

At 14 sites we took spot measurements of water temperature (ºC), specific conductance (µS/cm), dissolved oxygen concentration (mg/L) and saturation (%), and pH using a YSI WQS Pro-Plus hand-held water quality meter. Water quality readings were taken at only one of the four Anatimo Creek sites.

2.2.2. Periphyton

At six sites (Anatimo 1-4, Wainui River and Ellis Creek) periphyton was visually estimated by eye. At all other sites (except Burton Ale Creek, Little Onahau River and Anatoki River) the percentage cover of the stream bed by different categories of periphyton was assessed using the Rapid Assessment Method 2 (RAM-2) described by Biggs and Kilroy (2000). This method involves estimating the periphyton percentage cover on single stones at five points across the river on four transects within a 100 m reach of run habitat. Algae are classified according to their appearance. The percentage cover values are weighted according to the pollution tolerance of each algal classification, and then combined to give an overall periphyton enrichment score for the site ranging between 1 and 10 (1 indicating a site with highly degraded water quality and 10 representing a healthy site with excellent water quality).

2.2.3. Macroinvertebrates

At 12 sites a single semi-quantitative kick-net (0.5 mm mesh) sample was collected following sampling Protocol C1 (Stark et al. 2001). Each sample was transferred to a white tray for inspection. At Anatimo Creek (1-4), Wainui River and Ellis Creek, samples of live animals were processed *in situ* with the aid of a magnifying glass to minimise costs with sample processing. However, it became clear by the end of the first day that this method was too time-consuming, so on the second day of sampling the invertebrate samples were placed into a labelled 600 mL plastic pottle and preserved with 70% ethanol. Preserved samples were later processed in a laboratory using processing protocol P1 whereby the relative abundances of each taxa are estimated (Stark et al. 2001). Several indices of river ecosystem health were calculated from the data including species richness, EPT taxa (proportion of mayflies, stoneflies and caddisflies), the Macroinvertebrate community index (MCI) and the semi-quantitative MCI (SQMCI).

3. WATER QUALITY

3.1. Water temperature

Water temperature can affect the metabolic rates and biological activity of aquatic organisms. For example, temperatures exceeding the preferences of fish and invertebrates can have profound negative physiological effects. The physiological preference of eight common New Zealand native fish species ranges from 16 °C (smelt) to 26.9 °C (shortfin eel elver); most prefer temperatures between 18 °C and 22 °C (Richardson et al. 1994; see also a review by Olsen et al. (2011)). Brown trout are arguably more sensitive to high water temperatures than most, if not all, of our native fish species (Olsen et al. 2011). Some of New Zealand's most sensitive freshwater invertebrate species (i.e. some species of stoneflies and mayflies) are unable to survive temperatures exceeding 24 °C (Quinn & Hickey 1990; Quinn et al. 1994[1]).

Summer water temperatures can negatively interact with or influence other water quality parameters such as DO, pH and nutrients that reduce river water quality, thereby placing stress on instream fauna. Less water in a river can exacerbate the impact of temperature-related issues. Under drought condition, groundwater seeps (i.e. areas where groundwater upwells through the riverbed) may provide potential temperature refuge for animals (e.g. Matthews & Berg 1997) as river flows drop and available habitat contracts.

Spot water temperatures at the study sites ranged from 13 °C to 22 °C (Table 3)—levels within tolerance levels for fish and invertebrates. The lowest temperature was recorded in the Waikoropupu River at 7.30 am, and the highest in late afternoon (5.45 pm) at the Takaka River at Kotinga site*.* However, water temperature can vary greatly during the course of a day, and it is unlikely the daily extreme was captured at the sites. For example, the Aorere River temperature of 20 °C at 10.30 am was likely to have been much higher by mid-late afternoon. It is likely that fish will seek out thermal refuges during the times of day that temperatures peak, e.g. near groundwater seeps, or directly downstream of tributaries that have lower water temperatures than the surrounding river.

3.2. pH

Both very acidic (low pH) and very alkaline (high pH) water can have direct or indirect toxic effects on aquatic life. Environmental limits relating to pH for safeguarding aquatic life are generally defined as ranges (i.e. comprising a minimum and maximum). Most natural freshwaters have a pH in the range of 6.5−8.0 (ANZECC 2000). The ANZECC (2000) guidelines recommend default trigger pH ranges of 7.3 to

[1] For example, Quinn and Hickey found that 50% of *Deleatidium* in a temperature experiment died when subjected to a constant temperature of 24.5 °C for 2 days.

8.0 for upland rivers, and 7.2 to 7.8 for lowland rivers. Changes of more than 0.5 pH units from the natural seasonal maximum or minimum should be investigated. West et al. (1997) reported that the preferred pH range of most native New Zealand fish species is quite wide (generally around 6 to 10 or wider), although smelt have a much narrower preferred range (7.2 to 9.8).

The spot pH measurements in the Golden Bay rivers and streams ranged from 7.2 to 8.3 (Table 3). Although some pHs were above the recommended guidelines for lowland rivers, they were still within tolerances of New Zealand freshwater fish (including trout) and invertebrates (Hickey 2000; Hay et al. 2006). Diel fluctuations in pH result from algae and cyanobacteria and macrophytes photosynthesising during the daytime—causing increased alkalinity. Extreme pH fluctuations can occur when long periods of low, stable flow allow periphyton to accrue to high biomass.

3.3. Dissolved oxygen

Dissolved oxygen (DO) is critical for supporting aquatic life, and low concentrations can cause death—particularly for sensitive fish and aquatic organisms. As Davies-Colley and Wilcock (2004) explain, the DO concentration at any point in time is a balance between several processes, including:

1. oxygen consumed by aquatic life through respiration
2. oxygen produced through photosynthesis by aquatic plants and cyanobacteria
3. exchanges between the water and atmosphere. The re-aeration process in water is mostly controlled by the degree of turbulent mixing. A swift-flowing river is well re-aerated, whereas a sluggish one has poor uptake of atmospheric oxygen.

Dissolved oxygen can vary widely over a 24-hour period, especially in waterbodies with significant nutrient enrichment. As photosynthesis is light-dependent, DO peaks during daylight hours and declines at night. For this reason, as with water temperature, spot measurements of DO can be misleading if not put into context with the time of day the measurement was taken. Lowest levels of DO are normally at dawn just before photosynthesis (oxygen production) resumes. Generally, DO levels less than 6 mg/L (or 80% saturation) are considered insufficient to support sensitive fish (such as trout) and macroinvertebrates (mayflies, stoneflies and most caddis flies) (ANZECC 1992).

Reduced flow and consequent lower reaeration over riffles, compounded with high temperatures will reduce dissolved oxygen. As temperatures increase, the standard metabolic rate of fish increases, meaning higher oxygen consumption and demand (Olsen et al. 2011).

Table 3. Water quality measurements (temperature, dissolved oxygen, specific conductance and pH) for thirteen rivers and streams in the Golden Bay region. Measurements were taken on 6 or 7 of March 2019 at the end of a severe drought. GPS coordinates for each site are provided in Appendix 1. N/R indicates measurement not recorded.

	Anatimo 1	Anatimo 2	Anatimo 3	Anatimo 4	Wainui River	Ellis Creek	Waikoropupu River	Pariwhakaoho River	Aorere River
Date	06-Mar-19	06-Mar-19	06-Mar-19	06-Mar-19	06-Mar-19	06-Mar-19	07-Mar-19	07-Mar-19	07-Mar-19
Time	13:00	14:00	14:30	16:00	17:38	18:30	07:30	09:00	10:30
Temperature (℃)	14	N/R	N/R	N/R	18	20.6	13	15.5	20
DO (%)	120.1	N/R	N/R	N/R	128	102.1	115	92	93.7
DO (mg/L)	12.27	N/R	N/R	N/R	12.19	9.18	12.13	9.19	8.44
SPC (µS/cm)	106	N/R	N/R	N/R	99.7	198.8	134.4	165.2	83.8
pH	8.28	N/R	N/R	N/R	7.97	7.78	8.12	8.04	8.15

	Kaituna River at Queen's Farm bridge	Puremahaia River	Burton Ale Creek	Little Onahau River	Takaka River at gravel pit	Takaka River at Kotinga	Waingaro River
Date	07-Mar-19	07-Mar-19	07-Mar-19	07-Mar-19	07-Mar-19	07-Mar-19	07-Mar-19
Time	11:20	14:14	12:47	15:30	16:30	17:45	19:42
Temperature (℃)	18.5	17.1	19	21	19.3	22	20.5
DO (%)	84	78	79	85	110.5	123	105
DO (mg/L)	7.94	7.41	7.4	7.59	10.21	10.75	9.47
SPC (µS/cm)	139.4	71.9	686	42.8	132.5	126.8	125.2
pH	7.26	7.75	7.46	7.76	7.16	8.20	N/R

The spot DO measurements taken from the Golden Bay rivers and streams were all above 6 mg/L, and %DO saturation above 80% at all but two sites—Burton Ale Creek (which was hardly flowing) and Puremahaia River (Table 3). The DO mg/L values fell within the NPS-FM attribute bands of A or B for a 1-day summer minimum, 'A' being the highest level of protection. The category B attribute has DO boundaries of ≥ 5.0 mg/L and < 7.5 mg/L. Under this attribute, DO levels between these numeric values are considered to cause 'Occasional minor stress on sensitive organisms caused by short periods (a few hours each day) of lower dissolved oxygen. Risk of reduced abundance of sensitive fish and macroinvertebrate species' (MfE 2017). However, as mentioned above, spot DO measurements should be placed in context to time of day sampled. All measurements in our survey were taken during daylight hours when oxygen levels are generally peaking. It can be said that during the daytime, oxygen levels in the Golden Bay rivers and streams were within acceptable limits for maintenance of stream life. However, without knowledge of nocturnal or pre-dawn oxygen sags (i.e. the complete 24-hour DO cycle), it is not necessarily correct to assume that aquatic communities are unaffected by stress from low oxygen concentration.

3.4. Conductivity

Conductivity, in respect of water bodies, is a measure of the capability of water to pass electrical current, and hence it is related to the concentration of ions in the water. The more ions that are present, the higher the conductivity. Conductivity in streams and rivers is affected primarily by catchment geology. Agricultural runoff may increase conductivity due to the additional chloride, phosphate and nitrate ions. The mobility of ions, and related conductivity, in water increases with temperature. Because conductivity is temperature dependent it is commonly measured in µS/m referenced to 25 °C.

No guidelines currently exist that specifically set standards for change in conductivity in a stream. However, apart from Burton Ale Creek the conductivities recorded in the Golden Bay rivers and streams (Table 1) were in accordance with, or lower than, those of 95 rivers surveyed throughout New Zealand (Close & Davies-Colley 1990). In Burton Ale Creek the specific conductivity reading of 686 µS/cm was approximately 6x higher than the highest recorded for this creek (T James, TDC, pers. obs.). This may reflect reduced dilution of contaminants off the pasture catchment at the extreme low flow.

4. PERIPHYTON

The amount and types of periphyton (or algae) growing on the riverbed are also indicative of river ecosystem health (Biggs 2000). Excessive growth of filamentous green algae is typical in unshaded sites that have abundant nutrients. Long periods of low flow will exacerbate these effects. As the water velocities drop, so do near-bed shear stresses that would normally restrict native algal growth, encouraging long strands of filamentous algae and/or thick diatom/cyanobacterial mats on the riverbed to grow. These growths are often unsightly and can reduce the quality of habitat for other river life. In severe cases excessive algal growths can be a major contributor to DO sags, resulting in fish kills.

In more healthy systems, periphyton growths are dominated by thin films or mats of brown diatoms, which form an important food source for the macroinvertebrates that feed on them. As periphyton growth increases, a concurrent change in invertebrate community can also occur, from taxa generally associated with good water quality (e.g. mayflies and stoneflies) to taxa such as midge larvae (chironomids) and snails—taxa generally associated with poorer water quality,

Further up the food chain, trout and native fish may also be affected by excessive periphyton growth in the following ways. First, DO sags can result in DO minimum thresholds being breached. Second, the efficiency of visual drift feeding by trout and native galaxiids (e.g. koaro and banded kokopu) may be reduced by sloughed algae drifting in the water column. Third, as periphyton growth increases, invertebrate communities become dominated by small taxa (chironomid midge larvae and snails) which are less preferred, and energetically less profitable, to adult trout than larger, more drift-prone mayflies and stoneflies.

In most of the study's rivers or streams filamentous green algae was noted in shallow riffles but were absent from runs. This can be a natural occurrence especially in rivers with low nutrient concentrations, because the rate of nutrient transfer from the water to the periphyton is higher where water velocity is higher.

Other factors also affect periphyton growth such as light, temperature, and spatial variation in nutrient rich groundwater upwellings. Biggs (2000) provides trigger values for the protection of recreation and aesthetics (as well as trout habitat and angling) based on the percentage cover of filamentous green algae present in a river. Filamentous green algae coverage did not exceed the 30% guideline of Biggs (2000), with low coverage (< 15%) at all sites (Table 4, Appendix 3).

Table 4. Percentage contribution of long filamentous green algae cover at sites surveyed using the periphyton RAM-2 protocol at rivers site sampled in Golden Bay during the 2019 summer drought. N/R = not recorded.

Site name	% Long filamentous green algae
Anatimo 1 (above takes)	0.0
Anatimo 2 (above takes) (below takes - residual flow reach)	0.0
Anatimo 3 (below takes and residual flow reach)	0.0
Anatimo 4 (culvert below Robertson's dairy shed)	0.0
Wainui River	0.0
Ellis Creek	0.0
Waikoropupu River	13.0
Pariwhakaoho River	0.0
Aorere River	8.5
Kaituna River at Queen's Farm bridge	0.0
Puremahaia River	0.0
Little Onahau River	N/R
Takaka River at gravel pit	6.3
Takaka River at Kotinga	2.8
Burton Ale Creek	N/R
Anatoki River	N/R
Waingaro River	2.0

Periphyton scores at sites throughout the Golden Bay region ranged between 6.6 and 10 (Appendix 3); scores that reflected the periphyton communities at most sites were indicative of good water quality (i.e. there was no evidence of excessive algal growth). In Anatimo Creek there was evidence of a shift in periphyton community composition between the forested headwater sites (Anatimo 1 to 3) and the open pasture site (Anatimo 4). Algae at the forested sites largely consisted of thin diatom mats, while at the pastural site the algal biomass was higher (equal cover of thin and medium brown mats—Appendix 3).

Casual visual survey of longer reaches in the vicinity of the sample sites at which periphyton was surveyed with RAM-2 protocol suggested greater cover of green filamentous algae in the Kaituna Rivers than indicated by the data in Table 4. Green filamentous algae was also notable in the Little Onahau River (T. James, pers. obs.)

5. MACROINVERTEBRATES

5.1. Taxa richness

Taxonomic richness is the broadest measure of the state of an invertebrate community. High taxonomic richness indicates a diverse habitat able to support a range of species. Highly diverse ecosystems may be desirable because they can be more resilient to environmental disturbance and support a broader range of ecosystem functions (Elmqvist et al. 2003). Overall the invertebrate taxonomic richness at the study sites was relatively high for samples processed in the laboratory (Appendix 4). Taxonomic richness for the samples from Anatimo 1-4, Wainui River and Ellis Creek was lower. However, these samples were sorted *in situ*, so it is very likely some taxa were not detected because they were hidden in sample debris that could not easily be separated in the field. The high diversity of aquatic invertebrates was not surprising given the long period of stable flows in the study's rivers and streams prior to sampling, concentration of invertebrates in diminished habitat area at low flow, and moderate diversity of periphyton communities.

5.2. Mayfly, stonefly, caddisfly richness

EPT taxa are often used as an indication of water quality as these animals generally prefer unmodified streams with low levels of fine sediment and organic enrichment. Therefore, high richness of EPT taxa indicate high water quality and a relatively unmodified catchment (Stark et al. 1999). However, EPT taxa are also often more susceptible to environmental stressors such as elevated temperature and DO sags that would typically occur in rivers and streams during droughts.

The %EPT taxa across the sites ranged from 43–63% (Figure 3, Appendix 4), indicative of invertebrate communities that are relatively diverse and commonly seen in long duration, low flow conditions. In Anatimo Creek, %EPT taxa was similar among the forested headwaters sites (Anatimo 1 to 3) (Figure 3, Appendix 4), and higher at the forested sites than at the open pasture site (Anatimo 4)—the latter being a reflection of the change in periphyton composition and biomass.

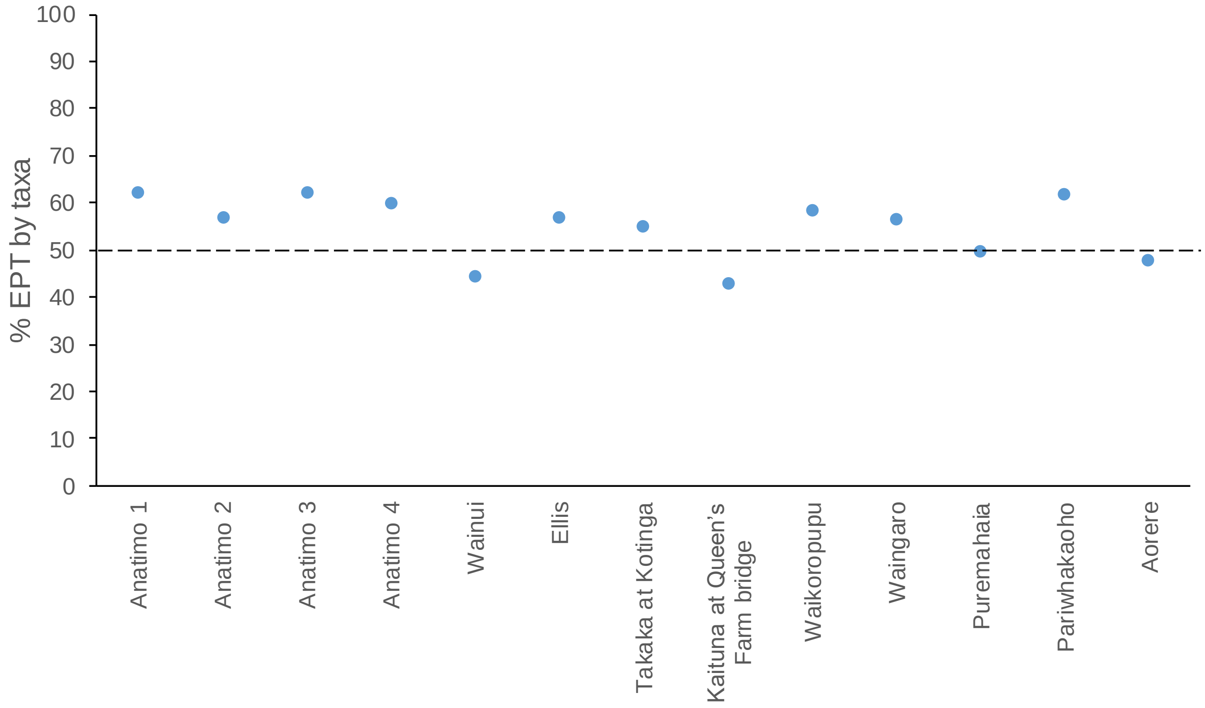

Figure 3. Percentage EPT by taxa for Golden Bay rivers and streams sampled during the 2019 summer drought. Dotted line indicates 50% mark. Note: the Aorere River datapoint was calculated from a SOE macroinvertebrate sample collected on 28 February 2019.

5.3. Macroinvertebrate Community Indices

MCI and SQMCI are biotic indices developed for assessing enrichment in stony streams and rivers (Stark 1985; 1998). Tolerance scores are assigned to invertebrate taxa ranging from 1 (tolerant to organic enrichment) to 10 (intolerant). The MCI is calculated from the tolerances scores for invertebrates present in the sample (Stark 1985). The SQMCI accounts for the presence of taxa and their relative abundance to each other (Stark 1993).

In theory, MCI values can range between 200 (when all taxa present score ten points each) and zero (when no taxa are present), but in practice it is rare to find MCI values greater than 150, and only extremely polluted, sandy/muddy sites or extremely disturbed substrate sites score under 50. SQMCI values range from 0 to 10, with scores above 5 indicating good (or excellent) water quality. The interpretation of index values when applied to stony streams throughout New Zealand is given in Table 5.

Table 5. Interpretation of MCI and SQMCI values from stony riffle streams (Stark & Maxted 2007)

	MCI	SQMCI
Excellent: Clean water	> 120	> 6,00
Good: Doubtful quality or possible mild pollution	100 – 119	5.00 – 6.00
Fair: Probable moderate pollution	80 – 99	4.00 – 4.99
Poor: Probable severe pollution	< 80	< 4,00

The MCI scores for the Golden Bay rivers and streams indicated water quality ranging from ‘Fair’ to ‘Excellent’ (Figure 4). The SQMCI values, for most of the sites, were in the same bands as the counterpart MCIs. Notable exceptions were the Wainui River (MCI: Good, SQMCI: Poor), Takaka River at Kotinga (MCI: Good, SQMCI: Fair) and Kaituna River at Queen’s Farm bridge (MCI: Good, SQMCI: Poor). In all such cases the SQMCI water quality status was lower than the MCI[2].

The MCI and SQMCI scores in Figure 4 appear to be typical of what might be expected in rivers under long duration, low flow stresses with moderate levels of algal growth. However, because this survey is the first time that many of these rivers and streams have been sampled, there are no comparative data to place the indices in context, i.e. what the communities are like under more typical flow conditions. The MCI and QMCI values at the Anatimo Creek sites reflected the differences in surrounding land use (Table 2), i.e. the water quality status of the upstream forested sites was ‘Excellent’ and downstream site located in open pasture ‘Fair’.

[2] The reason for the occasional discrepancy between MCI and SQMCI is explained in the following example. In the Wainui River nine taxa were recorded. Five of the taxa had an enrichment tolerance value of 5 or more, resulting in an MCI score of 102 (= good water quality). However, almost all these higher-scoring MCI taxa were ‘Rare’ in the sample (i.e. only 1 to 4 individuals). *Deleatidium* spp. (a common mayfly) was the only exception, being ‘Common’ in the sample (i.e. between 5 to 19 individuals). Of the four taxa left with MCI scores below 5, two of them were ‘Rare’, one was ‘Common’ and the other ‘Abundant’. So, in the Wainui River there were fewer low-scoring taxa, but those that were present were more abundant than the higher-scoring taxa. Overall, this resulted in a low SQMCI score of 3.64, and a lower water quality status relative to the MCI score from ‘Good’ to ‘Poor’.

It may seem that the SQMCI would be a more relevant index to use than the MCI—because it accounts for presence absence and relative abundance. However, both are important as each provides a different insight into what the structure of invertebrate communities can tell us. The MCI provides an indication of what the composition of the invertebrate community is. In the case of the Wainui River, it tells us that the community is diverse with a range of animals considered tolerant and intolerant to enrichment. A low-scoring MCI tells us that it is very likely we are losing high-scoring (usually EPT) taxa from the community. The SQMCI in the Wainui River tells us an additional part of the story—that abundance of the lower scoring taxa is greater relative to the higher scoring taxa.

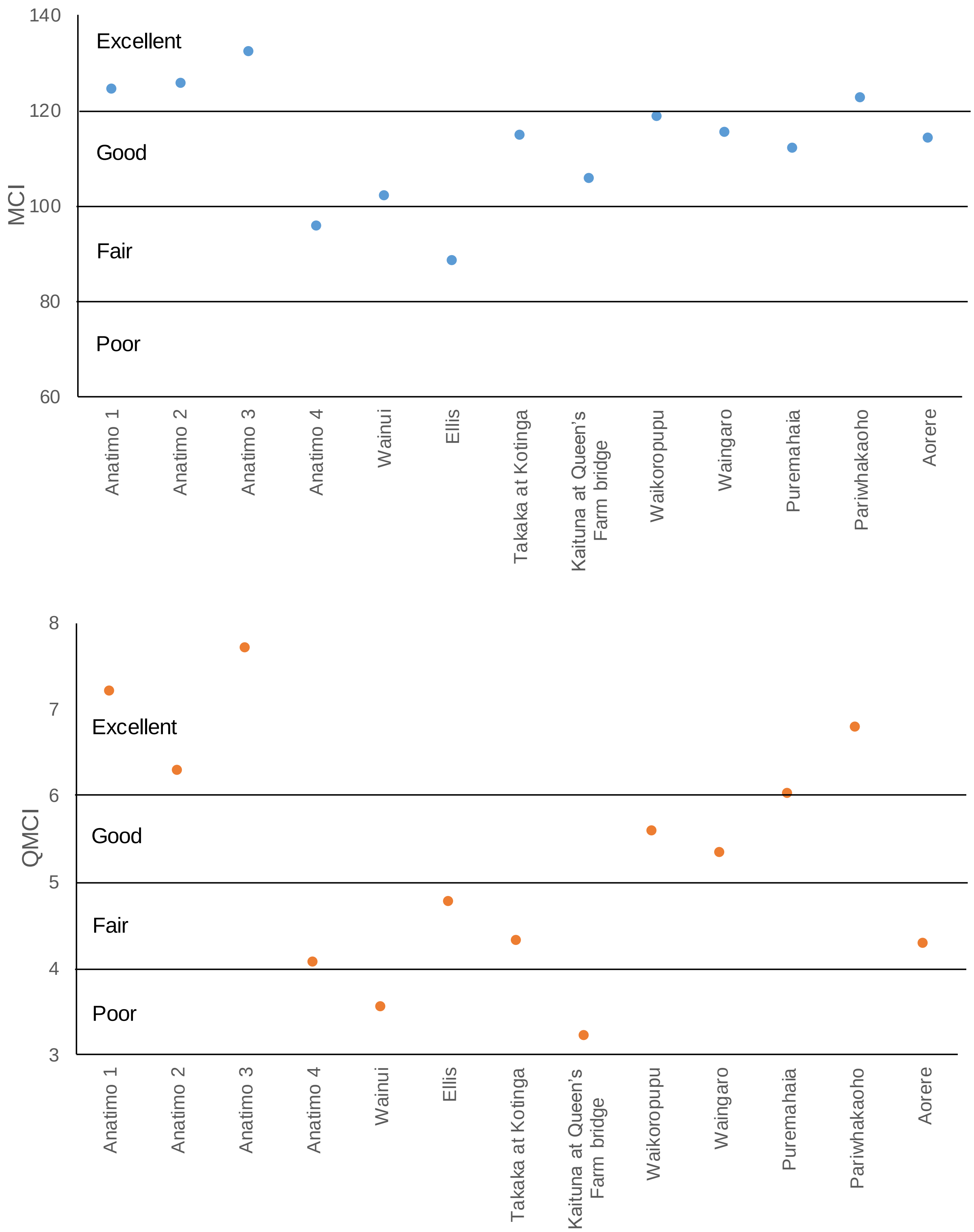

Figure 4. Macroinvertebrate Community Index (top graph) and semi-quantitative MCI (bottom graph) values for Golden Bay rivers and streams sampled during the 2019 summer drought. Water quality banding, as per Stark and Maxted (2007) boundaries, have been overlaid onto graphs (Excellent, Good, Fair, Poor). Note: the Aorere River datapoint was calculated from a SOE macroinvertebrate sample collected on 28 February 2019.

6. IMPLICATIONS OF SURVEY FOR MANAGEMENT OF TAKAKA FMU AND RECOMMENDATIONS

With the realities of climate change and continued human expansion, there is increasing demand on our water resources—with pressures exacerbated during times of drought. The ecological information presented within the report provides a rare record and valuable insight of how resilient river communities in the Takaka FMU are to an extreme natural low flow event. Coupled with hydrological and physical data also collected during the 2019 drought, these data provide TDC with the beginnings of a good baseline dataset that will aid in maintaining the delicate balance between the water requirements of the Tasman human community and the statutory requirements for safeguarding waterways in the Tasman region.

The water quality, periphyton and invertebrate results presented in this report are typical of what we would expect to see in rivers under drought conditions. Despite the drought, the periphyton and invertebrate communities were still relatively healthy (e.g. as measured by periphyton cover scores, invertebrate taxa richness, and MCI values). While this is reassuring, our results do not provide a complete picture of low flow effects on river/stream ecosystems. There are two important caveats to our findings:

1. Our ecological survey was confined to periphyton cover and broad community composition and macroinvertebrate community composition. It did not include an assessment of invertebrate and fish abundance, nor fish growth. When water quality is good, periphyton will not usually proliferate to nuisance levels and invertebrate diversity will be maintained during low flow conditions. This is the picture revealed by our study of the Golden Bay rivers and streams at the end of the 2019 drought. However, this does not imply no effect of the drought. The main hydrological effect is reduced flow, and this translates to reduced wetted area for supporting periphyton and benthic invertebrate production. The reduced wetted area and benthic production has potential adverse consequences for available suitable habitat and food supply for fish. Potential adverse effects on fish include reduced growth rate and abundance, the magnitude of effects increasing with the duration of low flows.
2. Our survey represents a single datapoint in time, and for many of the rivers/streams it is the only ecological information on record—thus we have no comparative data at other river flows.

We recommended the following:

1. That TDC collates any fish survey data collected during or within a year after the 2019 drought from Golden Bay rivers and streams and compares species presence absence and any abundance data available with historical data.
2. That at least two further water quality and ecological surveys of the study rivers and streams are undertaken to provide better environmental context, i.e. find out how the water quality, periphyton and invertebrate communities under drought

condition compare to more ‘typical’ flow conditions. One survey should be around the mean annual low flow (MALF) and another at around median flow (these flow statistics are most often used to reference instream in assessment of effects of flow on periphyton, invertebrates and fish (Jowett et al 2008; Hayes et al. 2018)

3. Collection of the following water quality and physical data including, 1) continuous DO, 2) continuous temperature, 3) wetted width (and/or area), and 4) flow. Continuous DO and temperature would be collected at representative sites surveyed in this study (i.e. sites will be grouped (e.g. by river type or stream size), and a selection chosen for DO/temperature meter placement). These data would allow biological data to be placed in better context of some of the major effects of river flow change on ecosystem function and habitat.

The above surveys would:

- enable the 2019 drought ecological survey results to be placed in context with other flows (between median and MALF), providing data of how resilient rivers and streams in the Takaka FMU are to low flow stress under current land use practices
- provide ecological baseline information for the rivers and streams that are not included in TDC’s annual State of the Environment monitoring programme
- inform TDC on the likely ecological status of rivers and streams at different flows for setting and meeting statutory targets under the NPS-FM to safeguard fresh water’s life-supporting capacity, ecosystem processes, and indigenous species, which in turn will
- aid water mangers in making informed, robust decisions on minimum flow and allocation limits.

7. ACKNOWEDGEMENTS

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9. APPENDICES

Appendix 1. Map coordinates (NZTM) of ecological survey sample sites.

Sites	GPS co-ordinates (NZTM)	
	Easting	Northing
Anatimo 1 (above takes)	1596104	5479692
Anatimo 2 (below takes - residual flow reach)	1596084	5479728
Anatimo 3 (below takes and residual flow reach)	1595956	5479755
Anatimo 4 (culvert below Robertson's dairy shed)	1595426	5480267
Wainui River	1594718	5479427
Ellis Creek	1589385	5479361
Waikoropupu River	1579630	5477766
Pariwhakaoho River	1577727	5484038
Aorere River	1569659	5498127
Kaituna River at Queen's Farm bridge	1567367	5492927
Puremahaia River	1578446	5483331
Burton Ale Creek	1571396	5496382
Little Onahau River	1580551	5481590
Takaka River at gravel pit	1582388	5477781
Takaka River at Kotinga	1583392	5476386
Anatoki River	1583142	5475815
Waingaro River	1583965	5474295

Appendix 2. Selection of site photos taken during ecological survey under drought conditions (March 2019).

Anatimo 4 (facing upstream from ford)

Wainui River (facing upstream from bridge)


Pariwhakaoho River (facing upstream from bridge)


Puremahaia River (facing upstream from bridge)

Little Onahau River (facing upstream from bridge)

Takaka River at gravel pit (facing upstream)

Waingaro River (facing upstream)

Appendix 3. Periphyton type and percentage cover of streambed at fourteen sites sampled in the Golden Bay region by either visual estimate of reach or using the RAM-2 Biggs & Kilroy (2000) methodology.

Sites	Description of algae and % cover
Anatimo 1 (above takes)	Thin light brown (50%) and thin black/dark brown mat (50%)
Anatimo 2 (below takes - residual flow reach)	Estimate not possible as too little water coverage of stream bed
Anatimo 3 (below takes and residual flow reach)	Thin light brown (50%) and thin black/dark brown mat (50%)
Anatimo 4 (culvert below Robertson's dairy shed)	Thin light brown (50%) and medium light brown mat (50%)
Wainui River	Thin light brown (60%) and medium green mat (40%)
Ellis Creek	Thin light brown (100%)

Waikoropupu River:

		Periphyton			Transect 1					Transect 2		
Stone/sample no:		**Score**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Thin mat/film:	Green	**7**										
(under 0.5 mm thick)	light brown	**10**	90		80		50			10		50
	black/dark brown	**10**										
Medium mat:	Green	**5**										
(0.5-3 mm thick)	light brown	**7**	10	95	15	95	50	100	40	40	100	50
	black/dark brown	**9**										
Thick mat:	green/light brown	**4**										
(over 3 mm thick)	black/dark brown	**7**										
Filaments, short	Green	**5**		5	5					20		
(under 2 cm long)	brown/reddish	**5**										
Filaments, long	Green	**1**				5			60	30		
(over 2 cm long)	brown/reddish	**4**										
Mean periphyton score:			9.7	6.9	9.3	6.7	8.5	7	3.4	5.1	7	8.5
% cover:			100	100	100	100	100	100	100	100	100	100
% cover by long filaments:			0	0	0	5	0	0	60	30	0	0
% cover by thick mats:			0	0	0	0	0	0	0	0	0	0

		Periphyton			Transect 3					Transect 4		
Stone/sample no:		**Score**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Thin mat/film:	Green	**7**										
(under 0.5 mm thick)	light brown	**10**	40		25	60	40			40	10	90
	black/dark brown	**10**										
Medium mat:	Green	**5**										
(0.5-3 mm thick)	light brown	**7**	60	50	50	40	60	20	100	30	45	10
	black/dark brown	**9**										
Thick mat:	green/light brown	**4**										
(over 3 mm thick)	black/dark brown	**7**										
Filaments, short	Green	**5**		25				20			20	
(under 2 cm long)	brown/reddish	**5**										
Filaments, long	Green	**1**		25	25			60		30	25	
(over 2 cm long)	brown/reddish	**4**										
Mean periphyton score:			8.2	5	6.25	8.8	8.2	3	7	6.4	5.4	9.7
% cover:			100	100	100	100	100	100	100	100	100	100
% cover by long filaments:			0	25	25	0	0	60	0	30	25	0
% cover by thick mats:			0	0	0	0	0	0	0	0	0	0

Overall mean periphyton score = 7.00
Overall % periphyton cover on stones = 100
Percentage cover by long green filaments = 13%
Percentage cover by thick mats = 0%

Pariwhakaoho River:

		Periphyton	Transect 1					Transect 2				
Stone/sample no:		**Score**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Thin mat/film:	Green	**7**										
(under 0.5 mm thick)	light brown	**10**	100	50		100	100	100	100	100	100	50
	black/dark brown	**10**		50	50							50
Medium mat:	Green	**5**										
(0.5-3 mm thick)	light brown	**7**										
	black/dark brown	**9**										
Thick mat:	green/light brown	**4**										
(over 3 mm thick)	black/dark brown	**7**										
Filaments, short	Green	**5**										
(under 2 cm long)	brown/reddish	**5**										
Filaments, long	Green	**1**										
(over 2 cm long)	brown/reddish	**4**										
Mean periphyton score:			10	10	10	10	10	10	10	10	10	10
% cover:			100	100	50	100	100	100	100	100	100	100
% cover by long filaments:			0	0	0	0	0	0	0	0	0	0
% cover by thick mats:			0	0	0	0	0	0	0	0	0	0

		Periphyton	Transect 3					Transect 4				
Stone/sample no:		**Score**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Thin mat/film:	Green	**7**										
(under 0.5 mm thick)	light brown	**10**	100	50	100	100	100	100	100	100	100	100
	black/dark brown	**10**		50								
Medium mat:	Green	**5**										
(0.5-3 mm thick)	light brown	**7**										
	black/dark brown	**9**										
Thick mat:	green/light brown	**4**										
(over 3 mm thick)	black/dark brown	**7**										
Filaments, short	Green	**5**										
(under 2 cm long)	brown/reddish	**5**										
Filaments, long	Green	**1**										
(over 2 cm long)	brown/reddish	**4**										
Mean periphyton score:			10	10	10	10	10	10	10	10	10	10
% cover:			100	100	100	100	100	100	100	100	100	100
% cover by long filaments:			0	0	0	0	0	0	0	0	0	0
% cover by thick mats:			0	0	0	0	0	0	0	0	0	0

Overall mean periphyton score = 10.00
Overall % periphyton cover on stones = 97.5
Percentage cover by long green filaments = 0%
Percentage cover by thick mats = 0%

Aorere River:

Stone/sample no:		Periphyton Score	Transect 1: 1	2	3	4	5	Transect 2: 1	2	3	4	5
Thin mat/film:	Green	**7**										
(under 0.5 mm thick)	light brown	**10**	75	70	50	20	50	85	50	50	10	45
	black/dark brown	**10**										
Medium mat:	Green	**5**										
(0.5-3 mm thick)	light brown	**7**		10								
	black/dark brown	**9**										
Thick mat:	green/light brown	**4**									10	
(over 3 mm thick)	black/dark brown	**7**										
Filaments, short	Green	**5**	25	20	25	10	15	15		25	5	10
(under 2 cm long)	brown/reddish	**5**										
Filaments, long	Green	**1**			25	20	15		50	25	25	10
(over 2 cm long)	brown/reddish	**4**										
Moss						50	20				50	35
Mean periphyton score:			8.75	8.7	6.5	5.4	7.4	9.3	5.5	6.5	3.8	7.8
% cover:			100	100	100	50	80	100	100	100	50	65
% cover by long filaments:			0	0	25	20	15	0	50	25	25	10
% cover by thick mats:			0	0	0	0	0	0	0	0	10	0

Stone/sample no:		Periphyton Score	Transect 3: 1	2	3	4	5	Transect 4: 1	2	3	4	5
Thin mat/film:	Green	**7**	Not recorded as run too deep to cross									
(under 0.5 mm thick)	light brown	**10**										
	black/dark brown	**10**										
Medium mat:	Green	**5**										
(0.5-3 mm thick)	light brown	**7**										
	black/dark brown	**9**										
Thick mat:	green/light brown	**4**										
(over 3 mm thick)	black/dark brown	**7**										
Filaments, short	Green	**5**										
(under 2 cm long)	brown/reddish	**5**										
Filaments, long	Green	**1**										
(over 2 cm long)	brown/reddish	**4**										
Moss												
Mean periphyton score:			0	0	0	0	0	0	0	0	0	0
% cover:			0	0	0	0	0	0	0	0	0	0
% cover by long filaments:			0	0	0	0	0	0	0	0	0	0
% cover by thick mats:			0	0	0	0	0	0	0	0	0	0

Note: Averages are based on only 10 stones

Overall mean periphyton score = 6.96
Overall % periphyton cover on stones = 42.3
Percentage cover by long green filaments = 8.5%
Percentage cover by thick mats = 0.5%

Kaituna River at Queen's Farm bridge:

		Periphyton			**Transect 1**					**Transect 2**		
Stone/sample no:		**Score**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Thin mat/film:	Green	**7**										
(under 0.5 mm thick)	light brown	**10**										
	black/dark brown	**10**										
Medium mat:	Green	**5**										
(0.5-3 mm thick)	light brown	**7**	100	100	100	100	75	10	100	100	100	100
	black/dark brown	**9**										
Thick mat:	green/light brown	**4**										
(over 3 mm thick)	black/dark brown	**7**										
Filaments, short	Green	**5**										
(under 2 cm long)	brown/reddish	**5**										
Filaments, long	Green	**1**										
(over 2 cm long)	brown/reddish	**4**										
Moss							25	90				
Mean periphyton score:			7	7	7	7	7	7	7	7	7	7
% cover:			100	100	100	100	75	10	100	100	100	100
% cover by long filaments:			0	0	0	0	0	0	0	0	0	0
% cover by thick mats:			0	0	0	0	0	0	0	0	0	0

		Periphyton			**Transect 3**					**Transect 4**		
Stone/sample no:		**Score**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Thin mat/film:	Green	**7**										
(under 0.5 mm thick)	light brown	**10**										
	black/dark brown	**10**			40				10			
Medium mat:	Green	**5**										
(0.5-3 mm thick)	light brown	**7**	100	100	60	100	50	90	90	100	100	10
	black/dark brown	**9**										
Thick mat:	green/light brown	**4**										
(over 3 mm thick)	black/dark brown	**7**										
Filaments, short	Green	**5**						10				
(under 2 cm long)	brown/reddish	**5**										
Filaments, long	Green	**1**										
(over 2 cm long)	brown/reddish	**4**										
Moss							50					90
Mean periphyton score:			7	7	8.2	7	7	6.8	7.3	7	7	7
% cover:			100	100	100	100	50	100	100	100	100	10
% cover by long filaments:			0	0	0	0	0	0	0	0	0	0
% cover by thick mats:			0	0	0	0	0	0	0	0	0	0

Overall mean periphyton score = 7.07
Overall % periphyton cover on stones = 87.3
Percentage cover by long green filaments = 0%
Percentage cover by thick mats = 0%

Puremahaia River:

		Periphyton	Transect 1					Transect 2				
Stone/sample no:		**Score**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Thin mat/film:	Green	**7**										
(under 0.5 mm thick)	light brown	**10**	100	100	100	100	100	100	100	100	100	100
	black/dark brown	**10**										
Medium mat:	Green	**5**										
(0.5-3 mm thick)	light brown	**7**										
	black/dark brown	**9**										
Thick mat:	green/light brown	**4**										
(over 3 mm thick)	black/dark brown	**7**										
Filaments, short	Green	**5**										
(under 2 cm long)	brown/reddish	**5**										
Filaments, long	Green	**1**										
(over 2 cm long)	brown/reddish	**4**										
Moss												
Mean periphyton score:			10	10	10	10	10	10	10	10	10	10
% cover:			100	100	100	100	100	100	100	100	100	100
% cover by long filaments:			0	0	0	0	0	0	0	0	0	0
% cover by thick mats:			0	0	0	0	0	0	0	0	0	0

		Periphyton	Transect 3					Transect 4				
Stone/sample no:		**Score**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Thin mat/film:	Green	**7**										
(under 0.5 mm thick)	light brown	**10**	100	100		90	100	100	100	100	100	100
	black/dark brown	**10**										
Medium mat:	Green	**5**										
(0.5-3 mm thick)	light brown	**7**										
	black/dark brown	**9**			100							
Thick mat:	green/light brown	**4**										
(over 3 mm thick)	black/dark brown	**7**										
Filaments, short	Green	**5**										
(under 2 cm long)	brown/reddish	**5**										
Filaments, long	Green	**1**										
(over 2 cm long)	brown/reddish	**4**										
Moss						10						90
Mean periphyton score:			10	10	9	10	10	10	10	10	10	10
% cover:			100	100	100	90	100	100	100	100	100	100
% cover by long filaments:			0	0	0	0	0	0	0	0	0	0
% cover by thick mats:			0	0	0	0	0	0	0	0	0	0

Overall mean periphyton score = 9.95
Overall % periphyton cover on stones = 99.5
Percentage cover by long green filaments = 0%
Percentage cover by thick mats = 0%

Takaka River at gravel pit:

Stone/sample no:		Periphyton Score	Transect 1: 1	2	3	4	5	Transect 2: 1	2	3	4	5
Thin mat/film:	green	**7**	50	40	75	40	100	100	100	90	100	100
(under 0.5 mm thick)	light brown	**10**										
	black/dark brown	**10**										
Medium mat:	green	**5**										
(0.5-3 mm thick)	light brown	**7**										
	black/dark brown	**9**										
Thick mat:	green/light brown	**4**										
(over 3 mm thick)	black/dark brown	**7**										
Filaments, short	green	**5**	50		20					10		
(under 2 cm long)	brown/reddish	**5**										
Filaments, long	green	**1**		60	5	60						
(over 2 cm long)	brown/reddish	**4**										
Mean periphyton score:			6	3.4	6.3	3.4	7	7	7	6.8	7	7
% cover:			100	100	100	100	100	100	100	100	100	100
% cover by long filaments:			0	60	5	60	0	0	0	0	0	0
% cover by thick mats:			0	0	0	0	0	0	0	0	0	0

Stone/sample no:		Periphyton Score	Transect 3: 1	2	3	4	5	Transect 4: 1	2	3	4	5
Thin mat/film:	green	**7**	100	100	100	100	100	100	100	100	80	100
(under 0.5 mm thick)	light brown	**10**										
	black/dark brown	**10**									20	
Medium mat:	green	**5**										
(0.5-3 mm thick)	light brown	**7**										
	black/dark brown	**9**										
Thick mat:	green/light brown	**4**										
(over 3 mm thick)	black/dark brown	**7**										
Filaments, short	green	**5**										
(under 2 cm long)	brown/reddish	**5**										
Filaments, long	green	**1**										
(over 2 cm long)	brown/reddish	**4**										
Mean periphyton score:			7	7	7	7	7	7	7	7	7.6	7
% cover:			100	100	100	100	100	100	100	100	100	100
% cover by long filaments:			0	60	5	60	0	0	0	0	0	0
% cover by thick mats:			0	0	0	0	0	0	0	0	0	0

Overall mean periphyton score = 6.58
Overall % periphyton cover on stones = 100
Percentage cover by long green filaments = 6.3%
Percentage cover by thick mats = 0%

Takaka River at Kotinga:

		Periphyton			Transect 1					Transect 2		
Stone/sample no:		**Score**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Thin mat/film:	green	**7**	30	60	20		20	20				20
(under 0.5 mm thick)	light brown	**10**	60	25	45	40	60	35	100	40	55	75
	black/dark brown	**10**										
Medium mat:	green	**5**										
(0.5-3 mm thick)	light brown	**7**						15		50		
	black/dark brown	**9**										
Thick mat:	green/light brown	**4**	10	10	5		10	10			3	5
(over 3 mm thick)	black/dark brown	**7**										
Filaments, short	green	**5**		5	30	25	10	15		10	42	
(under 2 cm long)	brown/reddish	**5**										
Filaments, long	green	**1**										
(over 2 cm long)	brown/reddish	**4**				35		5				
Mean periphyton score:			8.5	7.35	7.6	6.65	8.3	7.3	10	8	7.72	9.1
% cover:			100	100	100	100	100	100	100	100	100	100
% cover by long filaments:			0	0	0	35	0	5	0	0	0	0
% cover by thick mats:			10	10	5	0	10	10	0	0	3	5

		Periphyton			Transect 3					Transect 4		
Stone/sample no:		**Score**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Thin mat/film:	green	**7**	30		20					30	20	20
(under 0.5 mm thick)	light brown	**10**	45	70	40	60	80	80	70	70	70	70
	black/dark brown	**10**										
Medium mat:	green	**5**										
(0.5-3 mm thick)	light brown	**7**	10	27		15	20	20	15		10	10
	black/dark brown	**9**										
Thick mat:	green/light brown	**4**	15	3		25			15			
(over 3 mm thick)	black/dark brown	**7**										
Filaments, short	green	**5**			25							
(under 2 cm long)	brown/reddish	**5**										
Filaments, long	green	**1**			15							
(over 2 cm long)	brown/reddish	**4**										
Mean periphyton score:			7.9	9.01	6.8	8.05	9.4	9.4	8.65	9.1	9.1	9.1
% cover:			100	100	100	100	100	100	100	100	100	100
% cover by long filaments:			0	0	15	0	0	0	0	0	0	0
% cover by thick mats:			15	3	0	25	0	0	15	0	0	0

Overall mean periphyton score = 8.35
Overall % periphyton cover on stones = 100
Percentage cover by long green filaments = 2.8%
Percentage cover by thick mats = 5.6%

Waingaro River:

		Periphyton	Transect 1					Transect 2				
Stone/sample no:		**Score**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Thin mat/film:	green	**7**										
(under 0.5 mm thick)	light brown	**10**	95	90	100	100	60	100	90	60	50	60
	black/dark brown	**10**										
Medium mat:	green	**5**										
(0.5-3 mm thick)	light brown	**7**	5	10			30			20	50	30
	black/dark brown	**9**										
Thick mat:	green/light brown	**4**								10		
(over 3 mm thick)	black/dark brown	**7**										
Filaments, short	green	**5**										
(under 2 cm long)	brown/reddish	**5**										
Filaments, long	green	**1**					10		10	10		10
(over 2 cm long)	brown/reddish	**4**										
Mean periphyton score:			9.85	9.7	10	10	8.2	10	9.1	7.9	8.5	8.2
% cover:			100	100	100	100	100	100	100	100	100	100
% cover by long filaments:			0	0	0	0	10	0	10	10	0	10
% cover by thick mats:			0	0	0	0	0	0	0	10	0	0

		Periphyton	Transect 3					Transect 4				
Stone/sample no:		**Score**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Thin mat/film:	green	**7**										
(under 0.5 mm thick)	light brown	**10**	100	30	20	90	80	100	70	20	50	
	black/dark brown	**10**										
Medium mat:	green	**5**										
(0.5-3 mm thick)	light brown	**7**		70	80	10	15		30	80	50	100
	black/dark brown	**9**										
Thick mat:	green/light brown	**4**					5					
(over 3 mm thick)	black/dark brown	**7**										
Filaments, short	green	**5**										
(under 2 cm long)	brown/reddish	**5**										
Filaments, long	green	**1**										
(over 2 cm long)	brown/reddish	**4**										
Mean periphyton score:			10	7.9	7.6	9.7	9.25	10	9.1	7.6	8.5	7
% cover:			100	100	100	100	100	100	100	100	100	100
% cover by long filaments:			0	0	0	0	0	0	0	0	0	0
% cover by thick mats:			0	0	0	0	5	0	0	0	0	0

Overall mean periphyton score = 8.91
Overall % periphyton cover on stones = 100
Percentage cover by long green filaments = 2.0%
Percentage cover by thick mats = 0.8%

Appendix 4. Macroinvertebrates collected from streams/rivers in Golden Bay using a kicknet (0.5 mm mesh). Relative abundance scores: R = rare (1–4 individuals), C = common (5–19 individuals), A = abundant (20–99 individuals), VA = very abundant (100–499 individuals), VVA = very, very abundant (500+ individuals).

Taxa	MCI taxon score	Anitomo 1 above takes 06-Mar-19	Anitomo 2 residual creek 06-Mar-19	Anitomo 3 below takes 06-Mar-19	Anitomo 4 downstream 06-Mar-19	Wainui River 06-Mar-19
Ephemeroptera (mayflies)						
Austroclima jollyae	**9**	-	-	-	-	-
Austroclima sepia	**9**	-	-	-	-	-
Austroclima sp.	**9**	-	-	R	-	-
Coloburiscus humeralis	**9**	C	R	C	-	-
Deleatidium spp.	**8**	VA	R	VA	A	C
Neozephlebia scita	**7**	-	-	-	-	-
Nesameletus sp.	**9**	A	-	R	-	-
Plecoptera (stoneflies)						
Austroperla cyrene	**9**	R	-	C	-	-
Stenoperla prasina	**10**	-	-	-	-	-
Stenoperla sp.	**10**	-	-	-	-	-
Zelandobius sp.	**5**	-	-	-	R	-
Zelandoperla decorata	**10**	-	-	-	-	-
Zelandoperla sp.	**10**	-	-	-	-	-
Megaloptera (dobsonflies)						
Archichauliodes diversus	**7**	R	R	R	-	R
Coleoptera (beetles)						
Elmidae	**6**	R	R	C	-	-
Hydraenidae	**8**	-	-	R	-	-
Scirtidae	**8**	-	-	-	-	-
Diptera (flies)						
Aphrophila neozelandica	**5**	-	-	R	-	R
Austrosimulium spp.	**3**	-	-	-	-	-
Ceratopogonidae	**3**	-	-	-	-	-
Empididae	**3**	-	-	-	-	-
Ephydrella sp.	**5**	-	-	-	-	-
Eriopterini	**9**	R	-	-	-	-
Maoridiamesa sp.	**3**	-	-	-	-	C
Muscidae	**3**	-	-	-	-	-
Orthocladiinae	**2**	-	-	-	A	A
Paradixa sp.	**4**	-	-	-	-	-
Paralimnophila skusei	**6**	-	-	-	R	-
Polypedilum sp.	**3**	-	-	-	-	-
Scatella sp.	**7**	-	-	-	-	-
Tanypodinae	**5**	-	-	-	-	-
Tanytarsus sp.	**3**	-	-	-	-	-

Appendix 4 continued…

Taxa	MCI taxon score	Anitomo 1 above takes 06-Mar-19	Anitomo 2 residual creek 06-Mar-19	Anitomo 3 below takes 06-Mar-19	Anitomo 4 downstream 06-Mar-19	Wainui River 06-Mar-19
Trichoptera (caddis flies)						
Beraeoptera roria	**8**	-	-	-	-	-
Confluens olingoides	**5**	-	-	-	-	-
Costachorema xanthopterum	**7**	-	-	-	-	-
Costachorema sp.	**7**	R	-	R	-	-
Helicopsyche sp.	**10**	-	-	-	-	-
Hudsonema alienum	**6**	-	-	-	-	-
Hudsonema amabile	**6**	R	R	R	R	-
Hydrobiosis clavigera	**5**	R	-	-	-	-
Hydrobiosis copis	**5**	-	-	-	-	-
Hydrobiosis gollanis	**5**	-	-	-	-	-
Hydrobiosis parumbripennis	**5**	-	-	-	-	-
Hydrobiosis spp.	**5**	-	R	R	-	-
Hydrobiosis umpripennis	**5**	-	-	-	R	-
Hydrochorema sp.	**9**	-	-	R	-	-
Hydropsyche (Aoteapsyche) spp.	**4**	A	-	C	-	R
Neurochorema confusum	**6**	-	-	-	-	-
Neurochorema forsteri	**6**	-	-	-	-	-
Neurochorema spp.	**6**	-	-	-	R	-
Olinga feredayi	**9**	R	-	-	-	R
Oxyethira albiceps	**2**	-	-	-	-	-
Psilochorema bidens	**8**	-	-	-	-	-
Psilochorema leptoharpax	**8**	-	-	-	-	-
Psilochorema macroharpax	**8**	-	-	-	-	-
Psilochorema spp.	**8**	-	-	-	-	-
Pycnocentria evecta	**7**	-	-	-	-	R
Pycnocentrodes sp.	**5**	C	-	-	A	-
Zelolessica cheira	**10**	-	-	-	-	-
Nematoda (roundworms)	**3**	-	-	-	-	-
Nemertea (proboscis worms)	**3**	-	-	-	-	-
Oligochaeta (worms)	**1**	R	-	R	A	R
Platyhelminthes (flatworms)	**3**	-	R	R	-	-
Mollusca (snails)						
Gyraulus sp.	**3**	R	-	-	-	-
Physa acuta	**3**	-	-	-	-	-
Potamopyrgus antipodarum	**4**	R	-	-	A	-
Crustacea (crustaceans)						
Amphipoda	**5**	-	-	-	-	-
Cladocera	**5**	-	-	-	-	-
Ostracoda	**3**	-	-	-	-	-
Coelenterata (hydra)						
Hydra sp.	**3**	-	-	-	-	-
Acarina (mites)	**5**	-	-	-	-	-
Collembola (springtails)	**6**	-	-	-	-	-
Number of taxa		16	7	16	10	9
%EPT by taxa		62.5	57.1	62.5	60.0	44.4
MCI		125	126	133	96	102
SQMCI		7.20	6.29	7.71	4.08	3.56

Appendix 4 continued…

Taxa	MCI taxon score	Ellis Creek 06-Mar-19	Takaka River at Kotinga 07-Mar-19	Kaituna River at Queen's Farm bridge 07-Mar-19	Waikoropupu River 07-Mar-19	Waingaro River 07-Mar-19	Puremahaia River 07-Mar-19	Pariwhakaoho River 07-Mar-19
Ephemeroptera (mayflies)								
Austroclima jollyae	**9**	-	R	-	-	R	-	-
Austroclima sepia	**9**	-	R	C	-	-	R	-
Austroclima sp.	**9**	-	A	A	C	C	A	R
Coloburiscus humeralis	**9**	-	R	C	A	R	-	C
Deleatidium spp.	**8**	R	VA	VA	VA	VVA	VA	VVA
Neozephlebia scita	**7**	-	-	C	-	-	-	C
Nesameletus sp.	**9**	-	R	-	R	R	-	-
Plecoptera (stoneflies)								
Austroperla cyrene	**9**	-	-	-	A	-	R	C
Stenoperla prasina	**10**	-	-	-	R	R	-	C
Stenoperla sp.	**10**	-	-	-	R	-	R	R
Zelandobius sp.	**5**	-	-	R	-	R	-	-
Zelandoperla decorata	**10**	-	-	-	-	-	-	R
Zelandoperla sp.	**10**	-	R	-	-	-	-	-
Megaloptera (dobsonflies)								
Archichauliodes diversus	**7**	-	R	C	C	R	R	C
Coleoptera (beetles)								
Elmidae	**6**	-	C	A	A	C	A	A
Hydraenidae	**8**	-	C	A	A	R	A	C
Scirtidae	**8**	-	-	-	-	-	C	-
Diptera (flies)								
Aphrophila neozelandica	**5**	-	-	C	C	R	-	R
Austrosimulium spp.	**3**	-	R	C	R	R	A	C
Ceratopogonidae	**3**	-	-	-	R	-	R	C
Empididae	**3**	-	-	R	-	-	A	R
Ephydrella sp.	**5**	-	-	-	-	R	-	-
Eriopterini	**9**	-	R	R	R	-	C	R
Maoridiamesa sp.	**3**	-	-	-	C	R	-	R
Muscidae	**3**	-	C	C	A	A	-	-
Orthocladiinae	**2**	-	VA	VA	A	A	A	A
Paradixa sp.	**4**	-	-	-	-	-	C	-
Paralimnophila skusei	**6**	-	-	-	-	-	R	R
Polypedilum sp.	**3**	-	-	-	R	-	A	C
Scatella sp.	**7**	-	-	R	-	-	-	-
Tanypodinae	**5**	-	A	A	R	A	-	-
Tanytarsus sp.	**3**	-	VA	A	VVA	VVA	VA	VA

Appendix 4 continued…

Taxa	MCI taxon score	Ellis Creek 06-Mar-19	Takaka River 07-Mar-19	Kaituna River at Queen's Farm bridge 07-Mar-19	Waikoropupu River 07-Mar-19	Waingaro River 07-Mar-19	Puremahaia River 07-Mar-19	Pariwhakaoho River 07-Mar-19
Trichoptera (caddis flies)								
Beraeoptera roria	**8**	-	R	-	A	C	R	C
Confluens olingoides	**5**	-	-	-	R	-	-	-
Costachorema xanthopterum	**7**	-	-	-	-	R	-	-
Costachorema sp.	**7**	-	-	-	R	C	-	R
Helicopsyche sp.	**10**	-	C	R	C	R	VA	C
Hudsonema alienum	**6**	-	-	-	R	-	-	R
Hudsonema amabile	**6**	-	-	-	R	-	A	C
Hydrobiosis clavigera	**5**	-	R	-	-	-	R	R
Hydrobiosis copis	**5**	-	C	R	R	C	-	C
Hydrobiosis gollanis	**5**	-	-	-	-	-	R	R
Hydrobiosis parumbripennis	**5**	R	-	-	R	-	-	-
Hydrobiosis spp.	**5**	-	A	A	A	A	A	A
Hydrobiosis umpripennis	**5**	-	R	-	-	R	-	-
Hydrochorema sp.	**9**	-	-	-	-	-	-	-
Hydropsyche (Aoteapsyche) spp.	**4**	A	VA	A	VA	VA	R	A
Neurochorema confusum	**6**	-	-	-	R	-	R	-
Neurochorema forsteri	**6**	-	-	R	-	-	R	-
Neurochorema spp.	**6**	-	R	R	C	R	R	R
Olinga feredayi	**9**	-	A	A	VA	A	C	VA
Oxyethira albiceps	**2**	-	A	VA	C	A	C	C
Psilochorema bidens	**8**	-	R	-	C	-	R	R
Psilochorema leptoharpax	**8**	-	-	-	-	R	-	-
Psilochorema macroharpax	**8**	-	R	-	-	-	-	R
Psilochorema spp.	**8**	-	C	R	A	C	C	C
Pycnocentria evecta	**7**	-	A	C	VVA	A	VVA	VA
Pycnocentrodes sp.	**5**	VA	VA	VA	A	A	VA	VA
Zelolessica cheira	**10**	-	-	-	-	-	-	R
Nematoda (roundworms)	**3**	-	-	R	R	-	-	-
Nemertea (proboscis worms)	**3**	-	R	C	-	-	R	-
Oligochaeta (worms)	**1**	R	VA	VVA	-	R	VA	R
Platyhelminthes (flatworms)	**3**	-	-	-	-	-	R	-
Mollusca (snails)								
Gyraulus sp.	**3**	-	C	-	-	-	-	-
Physa acuta	**3**	-	C	C	-	R	-	-
Potamopyrgus antipodarum	**4**	-	-	VA	C	-	C	A
Crustacea (crustaceans)								
Amphipoda	**5**	R	-	-	-	-	-	-
Cladocera	**5**	-	R	-	-	R	-	-
Ostracoda	**3**	C	A	R	-	-	-	-
Coelenterata (hydra)								
Hydra sp.	**3**	-	-	A	-	-	R	-
Acarina (mites)	**5**	-	R	C	C	A	-	-
Collembola (springtails)	**6**	-	-	-	-	-	R	-
Number of taxa		7	38	37	41	37	40	42
%EPT by taxa		57.1	52.6	43.2	58.5	56.8	50.0	61.9
MCI		89	115	106	119	116	112	123
SQMCI		4.77	4.33	3.22	5.59	5.34	6.02	6.80