EUTROPHICATION IN THE NEWPORT BAY-ESTUARY IN 2002: TRENDS IN THE ABUNDANCE OF NUISANCE MACROALGAE (SEAWEED) IN 1996-2002

Report to: Orange County Public Facilities & Resources Department

Alex Horne Associates

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AHA: 867 Bates Avenue, El Cerrito, California 94530. 510-525-4433 (FAX 510-527-1085), email: anywaters@attbi.com

SUMMARY

Eutrophication, an overabundance of nuisance seaweeds, was found to be an impairment of the beneficial uses of Newport Bay Estuary in 1993. Excess nitrate (up to 15 mg/L N) in San Diego Creek was the most likely cause of eutrophication. As part of the TMDL process, nitrate was targeted for reduction in the watershed. The abundance and species composition of large forms of attached macroalgae (seaweeds) has been measured since 1996 at up to 24 sites and at various times in the year. Unlike most familiar ocean species, estuarine nuisance seaweeds are annuals. In spring tiny resting stages grow rapidly in summer by which time they are large plants that can exceed 20 cm across. In fall they die and decay. In 2002 seaweeds were measured in spring and summer at 8 representative sites in the intertidal zone of Upper Newport Bay.

Trends over time in abundance and species of nuisance seaweeds. In 2002 nuisance algae biomass fell to 0.3 kg/m^2 (less than 20% of the 1966 value of 1.8 kg/m^2; excluding small brown algae). The largest amount of nuisance seaweed found anywhere was, as usual, *Ulva* (2.9 kg/m^2) in the central mudflat region of the estuary. The decline trend line was highly correlated with time ($R^2 = 0.97$) and statistically significant ($p = 0.003$). Including the small brown, non-nuisance algae, the mean peak 2002 biomass was either just above the trend line (August data only) or on the trend line (mean of July and August). However adjusted, all 2002 values were well below the 1996 baseline. Two genera of nuisance seaweeds *Ulva* (sea lettuce) and *Enteromorpha* (sea confetti) are still present in the intertidal zone of Upper Newport Bay. The small brown non-nuisance algae *Centroceras* occurred lower in the intertidal zone. In 1996 *Ulva* was the dominant form with large quantities occurring in the mud flats through the estuary. *Enteromorpha* was less abundant, although still important. By 2002 *Ulva* and *Enteromorpha* were much reduced at almost all sites and not found at all in the lower half of the estuary. *Ulva* is now important only in the freshest uppermost section of the three sections of Upper Newport Bay and *Enteromorpha* is scattered over the upper half of the estuary. The lower sections Upper Newport Bay are now essentially free of nuisance algae from the PCH Bridge up to the Salt Works Dike. *Centroceras* was originally present as a minor player but is now locally abundant in the lower central section above the constriction.

Nutrients. Some idea of how "well fed" the algae are and which nutrient limits their growth can be gained from examination of the cellular percentages and relative abundances of N and P and the N:P ratios. The main nuisance form *Ulva* had both low nitrogen content and a low N:P ratio, indicating nitrogen shortage. It is thus logical to ascribe the pronounced decline in nuisance seaweed to the efforts made to reduce nitrate in San Diego Creek. The small brown alga *Centroceras* was most common in the central section and had a higher nitrogen content with the lowest N:P values indicating that its abundance was partially controlled by other factors than nitrogen.

Recommendations. The current sampling be continued for 2003. Also recommended is that the in-situ temperature and oxygen monitoring carried out in 1997 be repeated since the nuisance biomass has fallen to levels where its impairment of beneficial uses was predicted to cease. A report based on the entire data set and including the associated parameters of nitrogen sources and their declines should be prepared and made widely available.

INTRODUCTION

The watershed of Newport Bay Estuary

Newport Bay consists of two sections, the Upper Bay, now a wildlife refuge and Lower Bay, now a marina. Freshwater containing relatively high amounts of nitrate (2-25 mg/L as N) enters the Upper Bay via San Diego Creek that drains about 122 square miles of urban, undeveloped and currently used or developed agricultural land in the cities of Irvine, Newport Beach and parts of Orange and Tustin. San Diego Creek contains very little phosphorus since the main source of its nutrients appears to be drainage from former fertilized farmland and current ornamental plantings. Runoff from these areas would typically pass through or over soils that remove phosphorus by binding to clay but allow the highly soluble nitrate to pass. Seawater with very small amounts of nitrate enters the estuary twice a day and due to the shallowness of the water the entire volume of the estuary is exchanged every few days. In many estuaries, such as San Francisco Bay complete exchange is a matter of months or even years. Thus any nitrate entering from San Diego Creek is rapidly diluted, so much so that the concentrations in the seaward end may not be enough to stimulate the growth of nuisance algae.

Nuisance seaweeds

Two genera of nuisance seaweeds *Ulva* (sea lettuce) and *Enteromorpha* (sea confetti), are present in the intertidal zone of Upper Newport Bay and in most other estuaries around the world. These two species, especially *Ulva* become superabundant in response to nutrient additions such as some kinds of sewage or agricultural runoff. However, no quantitative data exists on the abundance of seaweeds in this period. Anecdotal observations suggest that the situation in the entire Newport Bay was worse in the 1980s than the 1970s, which would correspond with the development of the city of Irvine following the establishment of the University of California campus there in the 1960s.

In the 1970-80 period seaweeds had become so abundant in Newport Bay that they were blamed for blocking the cooling systems of large boats in Lower Newport Bay. The consequent overheating destroyed at least one engine requiring expensive repairs. Common sense suggested that nutrients in San Diego Creek were at least in part responsible for the nuisance seaweed blooms. The Santa Ana Regional Water Quality Control Board, in conjunction with various environmental groups, reduced some obvious sources of nitrate input such as plant nurseries. Watering of well-fertilized potted plants resulted in rapid runoff of highly enriched water that flowed into the tributaries of San Diego Creek. It was relatively easy to alter watering and runoff practices to eliminate such discharges.

In 1996 an extensive survey was made of the quantities, distribution, and identities of the nuisance seaweeds in both Upper and Lower Newport Bay. Lower Newport Bay, a complex network of marinas formed an almost continuous concrete wall only occasionally pierced by a small sandy beach used for recreation. Floating docks and boats extended out into the shallow water. The shoreline bulkheads extended so far into the water that little sediment was exposed at low tides. The sandy or hard surfaces and a continuously flooded hydroperiod are poor places for the growth of the two main nuisance algae *Ulva* and *Enteromorpha*. Neither species was observed following extensive searches although some small patches of floating weed were seen. The main floating vegetable material was the bright red "petals" of bougainvillea, used extensively for ornamentation in the region. Small amounts of various marine algae grew on the docks but were mostly out competed by extensive growths of filtering animals such as clams and sponges.

This short report examines the data collected in 2002 and makes some limited comparisons with previous years. In particular the trend of the decline from 1995 to 2002 is presented and a comparison of the amount and distribution of the main nuisance algae, *Ulva*, sea lettuce is illustrated.

METHODS

Observations and collections

Macroalgae collections in 2002 were made in the intertidal zone in February and March and on 16 July and 24 August. No seaweeds were seen in the first two collection periods, as might be anticipated with an annual weed that blooms in mid-summer. At other times the seaweeds were collected the same manner as in previous years (AHA, 1996). As in 2001, samples were taken more frequently in time but at fewer stations than the original collections. In 2002 collections were made at the same 8 widely spaced sites as 2001. These sites were selected as being representative of the 24 original stations and the entire estuary. Daylight tides were not favorable in 2002 and in July station 24, was submerged and could not be sampled. For the same reason no samples were collected in September and October 2002.

At all sites triplicate randomly located samples were harvested. Seaweed was collected by hand from plastic quadrats of approximately 0.1 m^2 area, picked clean of any debris and snails, washed to remove mud using buckets of clean local seawater, spun damp dry in a field centrifuge, and immediately weighed on site using a field balance. Samples of seaweed needed for nitrogen and phosphorus content and dry weight analysis were treated similarly, enclosed in plastic bags, kept cool, and were delivered to the laboratory within a few hours of collection. Analysis of dry weight, nitrogen and phosphorus in samples was in accordance with Standard Methods (APHA, 1997).

RESULTS

TRENDS OVER TIME IN ABUNDANCE AND SPECIES OF NUISANCE SEAWEEDS1996-2002

Ulva and Enteromorpha. A summary of the biomass of the two nuisance algae *Ulva* and *Enteromorpha* between 1996 and 2002 is given in Figure 1-2 and Table 1. Details of the spatial and temporal distribution of each species of algae including *Centroceras* are given later in this section of the report.

Since quantitative measurements began in 1996, the annual average midsummer biomass of the nuisance seaweeds *Ulva* and *Enteromorpha* in Upper Newport Bay has fallen steadily at about 0.2 $kg/m^2/yr$ (Fig. 1). In 1996 nuisance seaweeds were extremely dense (1.8 kg/m^2), equivalent to about 20,000 ug/L of suspended chlorophyll *a* (a typical desirable chlorophyll value would be < 25 ug/L). The amount of seaweed was so large in 1966 that the nighttime respiration sometimes reduced the dissolved oxygen content of the estuary to levels dangerous to fish and wildlife. By 2001 the excessive eutrophication trend had been reversed and seaweed abundance had halved to 0.76 kg/m^2. The 2002 data show a continuation of much lower nuisance seaweed abundance (Fig. 1).

In 2002 nuisance algae biomass fell to 0.3 kg/m^2 (Table 1) or approximately 17% of the 1966 value of 1.8 kg/m^2 (excluding small brown algae *Centroceras*). The change was not only measurable but for the last two years the mudflats of the estuary have been visibly lower in green nuisance seaweeds. The changes are especially noticeable to the eye in the lower sections of the estuary where road access permits direct observation.

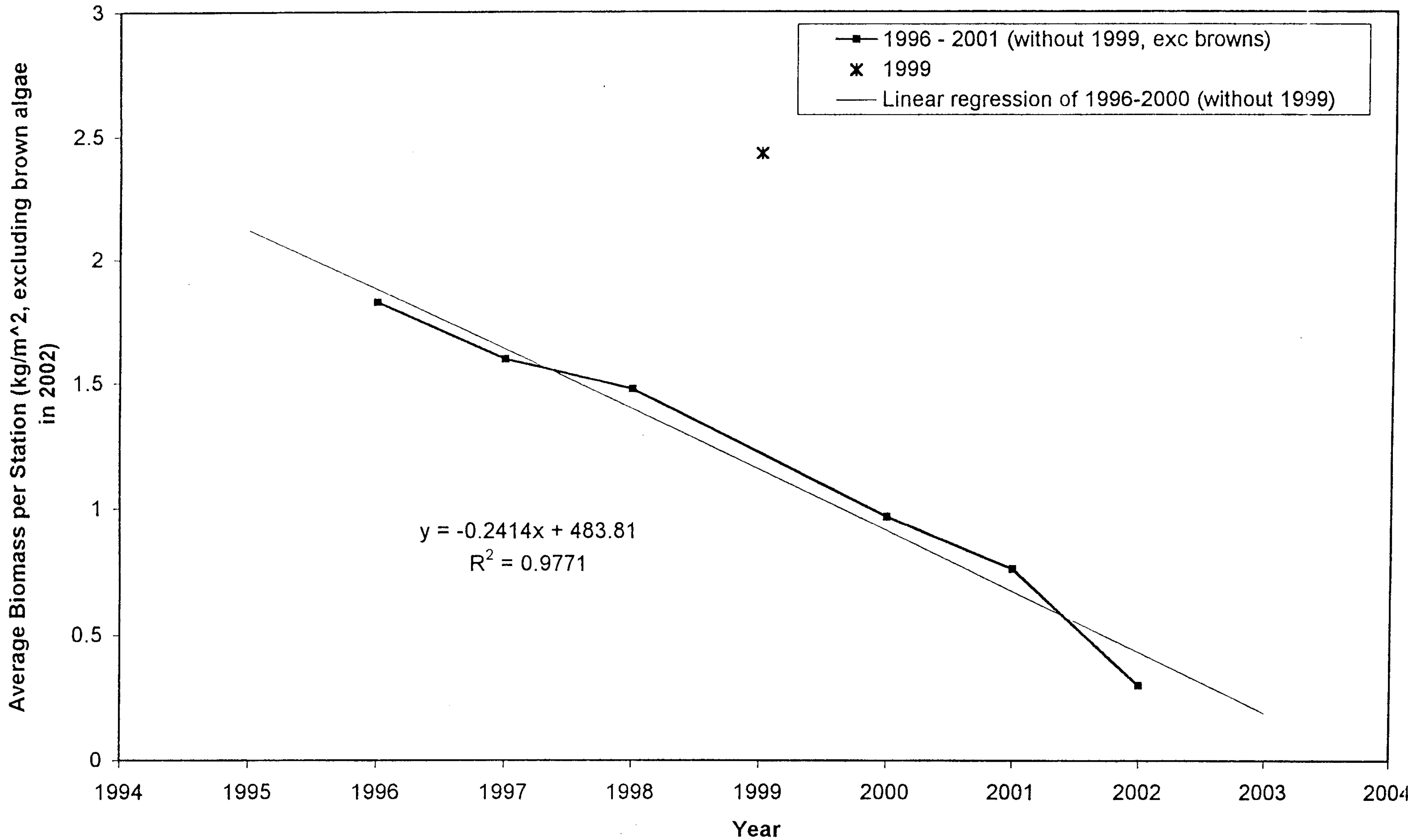
Table 1. Various ways of determining the mean declines in seaweed biomass for Upper Newport Bay 1996-2002. In the early years up to 24 stations were measured but various changes in the estuary meant that only 20 were sampled in the 96-99 period. Stations 1-3 became depauperate in any seaweed by 98 and tended to drag the mean values down.

Type of average	Percent change between Years						
	96-97	97-98	98-99	99-00	00-01	01-02	96-02
1. Mean	-13	-8	+65	-60	-21	-61	- 83[1]
2. 20 Stations	-15	-4	+58	-58	-	-	-
3. Omit 1-3	-11	-11	+60	-57	-	-	-
Average	**-13**	**-8**	**+61**	**-58**	**-21**	**-61**	**-83**

*Biomass over the three years has been averaged in three ways: (1) All data for each year (different # n), (2) Only similar stations (i.e. always same station numbers compared), and (3) Omit sta # 1-3 which are outside the main Upper Newport Bay. w = site washed away by El Nino floods, b = site too near skimmer colony, in = inaccessible for regular sampling (water too shallow for too long). [1]Excludes brown non-nuisance algae *Centroceras*.

As in past years, the largest single amount of nuisance seaweed found anywhere was *Ulva* at 2.9 kg/m^2 (Sta. 9-3) in the central mudflat region of the estuary. Three kg/m^2, a fresh volume about the size of a soccer ball, is still a large amount of nuisance biomass but can be compared to the single quadrat values of up to 6.5 kg/m^2 found in 1966 (Sta 11-3). Some idea of the spatial extent of the decline of *Ulva* can be seen if the distribution in 2002 is compared with the baseline value in 1996 (Fig. 2).

Fig. 1. Nuisance seaweeds *(Ulva* and *Enteromorpha)* in Upper Newport Bay, 1996-2002 (the dredging year 1999 is shown but not included in the regression)



The decline in *Ulva* over the last 6 years is especially dramatic in the lower part of the estuary. For example in 1996 the mean biomass of *Ulva* peaked at 3-4 kg/m^2 between stations 4 and 11 (Fig. 2). In contrast, in summer 2002 *Ulva* was either absent or present at less than 0.5 kg/m^2 over the same area. Where *Ulva* was more common in 2002, at stations 16-19 in the upper part of the estuary, it rose to only about 1 kg/m^2 relative to values of over 2.1 kg/m^2 in 1996 (Fig.2). Thus the decline of *Ulva* has been almost 100% in the lower estuary and at least 50% in the upper sections.

Changes in all seaweed biomass including *Centroceras*. The small brown non-nuisance alga, *Centroceras*, has always been present in the lower intertidal zone in Upper Newport Bay. In most previous years *Centroceras* was present as a minor algae, for example, a trace or absent at most sites and a maximum of 30% in one part of one site in 2001. In part due to the decline of the large green nuisance species, *Centroceras* has become more common and now plays a role in the overall biomass found in the estuary. Without *Centroceras* the average biomass in Upper Newport Bay in 2002 fell to 0.3 kg/m^2 but this value increases when *Centroceras* is included.

Including the non-nuisance species *Centroceras*, the mean peak 2002 biomass was either 1.09 kg/m^2 (late August peak) or 0.61 kg/m^2 (mean of July and August). Using the higher vale decline trend line remains well correlated with time ($R^2 = 0.81$) indicating that time alone explains 81% of the changes observed. If the 2002 mean of mid July and late August is used, approximating the sampling time in early years (late July), the trend line becomes even better correlated ($R^2 = 0.99$). Including *Centroceras*, the mean peak 2002 biomass was either just above the trend line (August data only) or on the trend line (mean of July and August). However adjusted, all 2002 values were well below the 1996 baseline of 1.8 mg/m^2.

Upper Newport Bay biomass distribution and species composition

Biomass Distribution and Amounts in 2002. A summary of the biomass data is given in Tables 1-2 and Figures 1-3. The amounts of each species of algae are given in this section and as a clumped mass later in the report.

Ulva, the sea lettuce, is the historically most common nuisance species in Newport Bay and many other nutrient-rich estuaries. The biomass of *Ulva* in 2002 averaged 0.06 kg/m^2 in mid-July and 0.17 kg/m^2 in late August (Fig. 3a, Table 1). Since daylight tides in fall 2002 were not conducive to intertidal sampling in the September and October it is not know if larger amounts of *Ulva* were produced later in the season. However, based on previous years, the July-August data probably spans the seasonal maximum and seaweeds are in decline in autumn. In 2002 *Ulva* was mostly confined to the upper half of Upper Newport Bay (stations 9-24). Peak abundance was 0.37 kg/m^2 (Sta. 13, July), 0.32 kg/m^2 (Sta. 16, Aug), and 0.98 kg/m^2 (Sta. 19, Aug). These mean and peak values are well below the peaks found in the early years (1996-98). In addition, station 16 is a "drift-influenced" site and represents both growth at the site and some drift of algae from other

Figure 2. Comparison of Ulva seaweed biomass in Upper Newport Bay (July 1996 vs July and August 2002). Biomass declined overall but most obviosly in the lower reaches

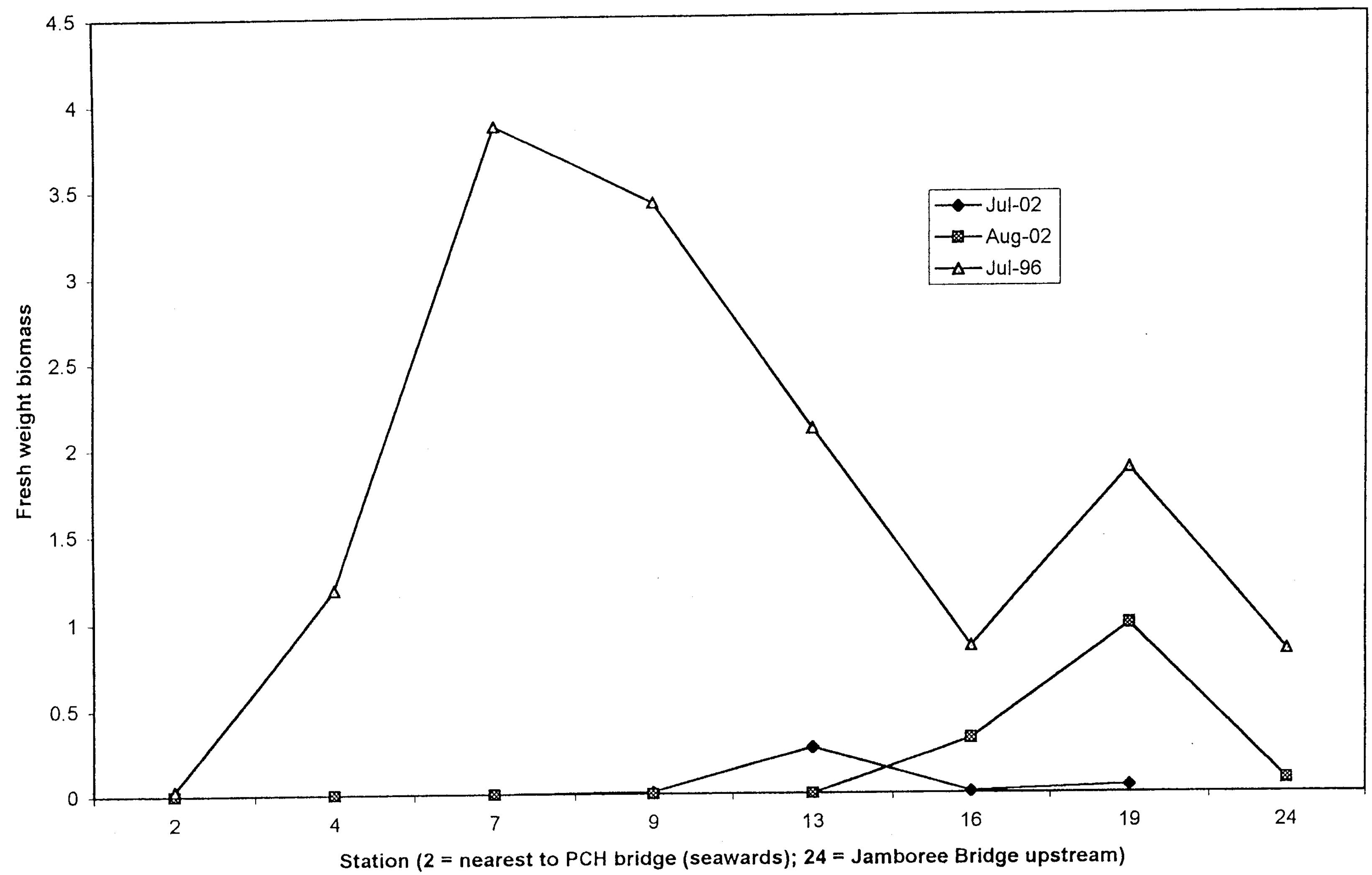


Figure 3a. Seasonal variation in biomass of the nuisance algae *Ulva* in Upper Newport Bay during 2002. Most growth is now restricted to late summer and in the uppermost region near the inflow of nitrate from San Diego Creek

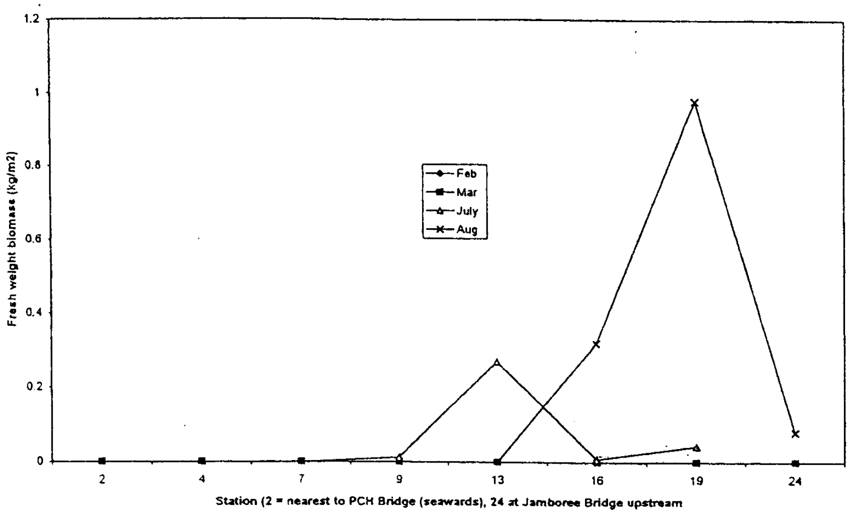


Fig. 3b. Seasonal variation in the biomass of the nuisance algae, Enteromorpha in Upper Newport Bay during 2002. Most growth is now restricted to the summer in the central-upper regions closest to the inflow of nitrate from San Diego Creek

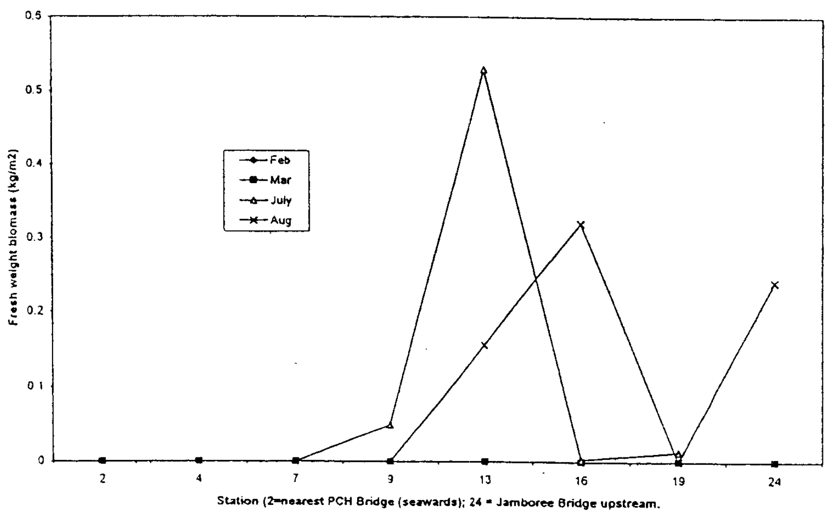
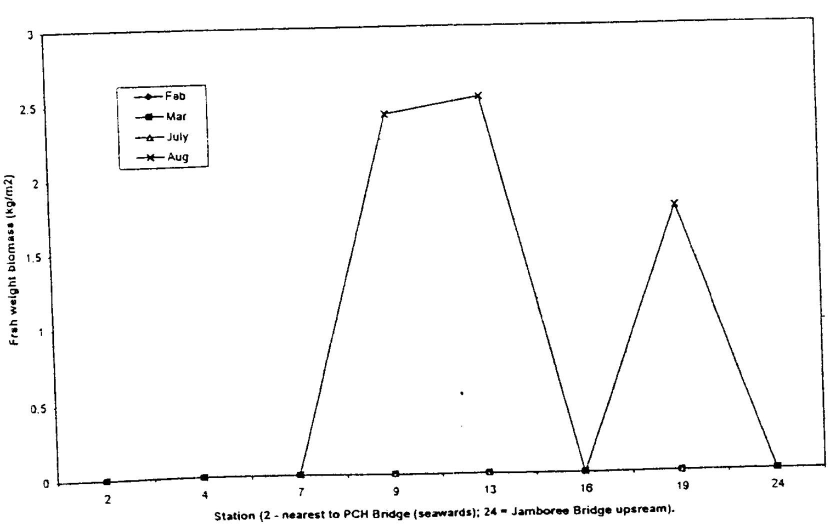


Fig. 3c. Seasonal variation in the biomass of the non-nuisance seaweed Centroceras in Upper Newport Bay in 2002. The small brown species bloomed inthe central section of the estuary in late summer and was less related to the nitrate input at Sta. 24.



sites. Station 16 is on the seaward-facing, downwind site of the Salt Works Dike and collects many drifting objects such as tennis balls and shoes as well as any drifting alga.

Enteromorpha, sea confetti is the second most common nuisance species found in Newport Bay. The biomass of *Enteromorpha* averaged 0.08 kg/m^2 in mid-July and 0.09 kg/m^2 in late August (Fig. 3b, Table 1). In 2002 *Enteromorpha* was, like *Ulva*, mostly confined to stations 9-24 or the upper half of Upper Newport Bay. Peak abundance was, again like *Ulva*, 0.53 kg/m^2 (Sta. 13, July) and 0.32 kg/m^2 (Sta. 16, Aug), and 0.24 kg/m^2 (Sta. 24, Aug). These mean and peak values are well below the peaks found in the early years (1996-98). In addition, station 16 is a "drift-influenced" site and represents both growth at the site and some drift of algae from other sites.

Table 1. Average biomass of the nuisance green algae *Ulva* and *Enteromorpha* and the non-nuisance brown algae *Centroceras* in the intertidal zone in Upper Newport Bay in 2002. Samples could not be collected in July at site 24 (nd) since it was the last station to be collected and was submerged.

Site	Biomass (kg/m^2)							
	Feb	March	July			Aug		
			Ulva	*Entro*	*Centro*	*Ulva*	*Entro*	*Centro*
2	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	2.41
9	0	0	0.012	0.049	0	0	0	2.52
13	0	0	0.37	0.53	0	0	0.156	0
16	0	0	0.008	0.003	0	0.32	0.32	1.77
19	0	0	0.043	0.001	0.001	0.98	0	0
24	0	0	Nd	nd		0.08	0.24	0
Mean	**0**	**0**	**0.062**	**0.083**	**0.0001**	**0.17**	**0.090**	**1.34**

Centroceras, a small brown macroalgae found somewhat deeper in the intertidal than the other species is not known as a nuisance species. As the nuisance algae declined, *Centroceras* became the most locally abundant form in a section of the central part of Upper Newport Bay (Sta. 7-9). *Centroceras* was rare in July 2002 but averaged 1.34 kg/m^2 in late August (Fig. 3c, Table 1). Unlike *Ulva* or *Enteromorpha, Centroceras* was confined to stations 7-16 or the central part of Upper Newport Bay. Peak abundance was about 2.5 kg/m^2 (Stations 7 and 9, August).

Previous reports have given seaweed data as a lump sum without distinguishing the relative contributions of each of the main species. This practice has been changed in 2002 since the two nuisance species *Ulva* and *Enteromorpha* no longer are the most common species, at least some times during the year. However, to facilitate comparisons with previous years the entire seaweed biomass is reported below and shown in Table 2.

Table 2. Biomass of total and nuisance algae in Upper Newport Bay during the growth period in 2002. Eight representative sites were chosen from the original 24 sites. Site 24 was submerged in July at collection time so no data was reported (nd). Weights are for all algae collected (nuisance + non-nuisance species), except where indicated.

Site	**Mean biomass mg wet wet/m^2**					
	Feb	March	July	Aug	July + Aug	**August Nuisance algae**
2	0	0	0	0	0	0
4	0	0	0	0	0	0
7	0	0	0	2.41	1.21	0
9	0	0	0.06	2.52	1.29	0
13	0	0	0.80	0.16	0.48	0.48
16	0	0	0.01	2.40	1.21	0.32
19	0	0	0.04	0.98	0.51	0.51
24	0	0	nd	0.27	0.27	0.27
Mean	**0**	**0**	**0.13**	**1.09**	**0.62**	**0.20**

The average peak (August) biomass of all species of macroalgae in Upper Newport Bay in summer 2002 was 1.09 kg/m^2 as fresh weight for the 8 stations sampled. Although only part of the season was surveyed in detail, the seasonal variation is shown in Figure 4a. As in previous years no seaweeds were seen in the early part of the year but averaged 0.13 kg/m^2 in mid July and that value rose to 1.09 kg/m^2 in late August. All previous collections were made in late July or very early August. If the mid-July and late August 2002 biomass values are averaged to approximate the previous year's late July collections the value is 0.62 kg/m^2 (Fig. 4b). Over the 2002 season, the individual single quadrat biomass estimated from all 45 collections when any algae were present ranged from 0.003 – 2.9 kg/m^2 and for the 8 station means the range was 0.04 – 2.5 kg/m^2. Peak biomass occurred in station 9, in the central mud-flat region of the estuary and station 16 which faces downwind (downstream) of large open water and the high biomass may have been enhanced with drift weed.

Considering the species individually, the seasonal pattern was a modest growth in the period March-July (~ 0.1 kg/m^2 for both *Ulva* and *Enteromorpha*) and a slight increase by August (Fig 4c). The small brown algae *Centroceras* showed a different pattern being virtually absent in July and probably peaking in August at a relatively high biomass (~ 0.85 kg/m^2, Fig. 4c).

Species composition and spatial distribution of seaweeds in 2002.

The percentage of the major algal species was also estimated from each quadrat and is shown in Tables 3a-b. As in all 7 years of quantitative record, three genera of attached macroalgae, the two green genera *Ulva* (sea lettuce), *Enteromorpha* (confetti) and the small brown form *Centroceras* were common in Newport Bay.

Two genera of nuisance seaweeds *Ulva* (sea lettuce) and *Enteromorpha* (sea confetti), are present in the intertidal zone of Upper Newport Bay. The small brown non-nuisance

Fig. 4c. Seasonal variation in biomass of the three main seaweeds in Upper Newport Bay in 2002

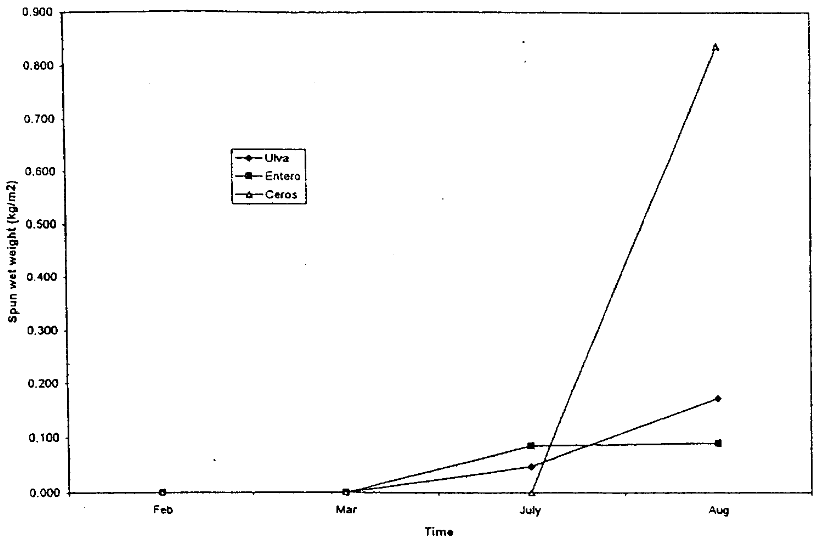


Fig. 4b. Seasonal variation in biomass of Nuisance Seaweeds in Upper Newport Bay in 2002

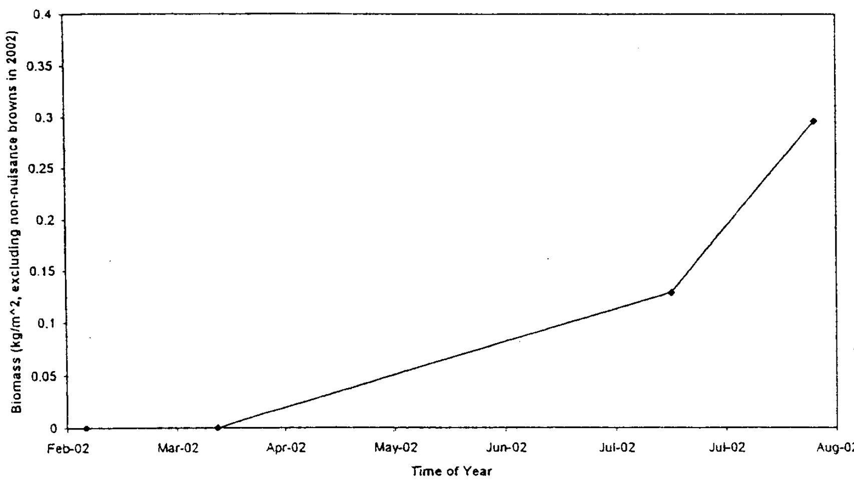
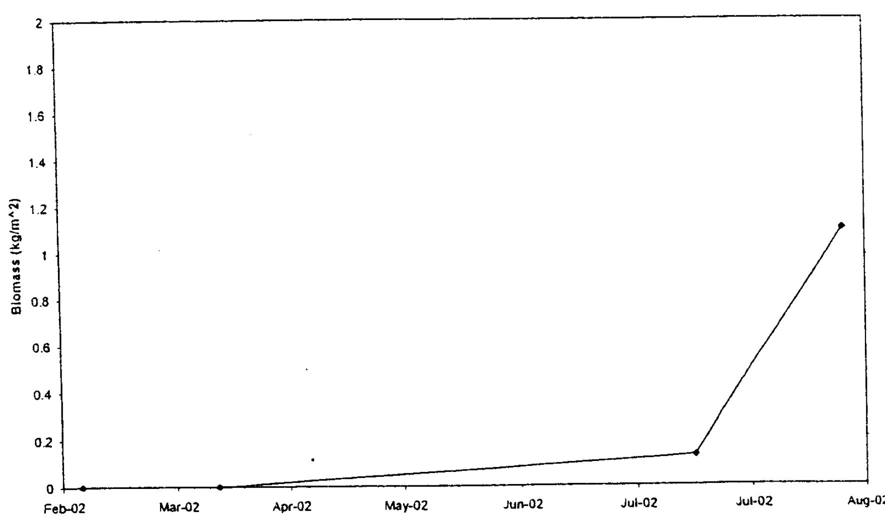


Fig 4a. Seasonal variation in average Biomass of all sewaweed algae in Upper Newport Bay in 2002



algae *Centroceras* was also found somewhat lower in the intertidal zone. *Ulva* was originally present in as the dominant form with large quantities occurring in the mud flats through the estuary including the lower sections. *Enteromorpha* was less abundant, although still found in large amounts relative to most estuaries. *Ulva* and *Enteromorpha* are now much reduced at almost all sites and are not found in the lower half of the estuary. *Ulva* is now important only in the freshest uppermost section of the three sections of Upper Newport Bay and *Enteromorpha* is scattered over the upper half of the estuary. The lower sections Upper Newport Bay are now essentially free of nuisance algae from the PCH Bridge up to the Salt Works Dike. *Centroceras* was originally present as a minor player but is now locally abundant in the lower central section above the constriction.

Ulva and *Enteromorpha* were both common in 2002, with *Ulva* present in 18 samples (64%) and *Enteromorpha* present in 17 samples (61%). As in previous years *Ulva* and *Enteromorpha* shared dominance in the muddy intertidal zone. *Ulva* dominated seaweed biomass in 9 samples (32%) and *Enteromorpha* dominated in 10 (36%). *Ulva* and *Enteromorpha* were co-dominant in only 1 (4%) of the samples. *Centroceras* was more common than in previous years and was present in 10 samples (36%). This small brown alga dominated the biomass in 9 samples (32%) in the central section in August (Stations 7, 9 and 16) in contrast to reaching only 30% in a single station in the previous years. Although not always present in large quantities, *Enteromorpha* tended to dominate in the central-upper parts of Upper Newport Bay and in mid-July. *Ulva* tended to dominate in the upper stations and in August.

Table 3A. Fresh biomass and species composition for macrophytes in Upper Newport Bay on 16 July 2002. The distance (dist) is distance in km from the estuary mouth; values for three replicates (a-c) and the mean are given in kg/m^2 fresh weight. The percentage composition of the dominant macroalgae in each replicate is shown as a percentage of the total (U = *Ulva*, E = *Enteromorpha*, C = *Centrocerus*).

Stn #	Dist.	Rep A	Rep B	Rep C	Mean	Rep A	Rep B	Rep C
2	5.8	0	0	0	0			
4	6.6	0	0	0	0			
7	7.4	0	0	0	0			
9	8.2	0.10	0.018	0	0.04	10%U, 90%E	70%U, 30%E	0
13	9.1	1.74	0.43	0.24	0.80	nd	20%U, 80%E	50%U, 50%E
16	9.2	0.006	0.026	0.003	0.012	20%U, 80%E	95%U, 5%E	100%E
19	10.2	0.044	0.02	0.068	0.044	97%U,2%E, 1% C	98%U, 2%E	95%U, 5%E
24	10.8	0	0	0	0			
Mean					**0.13**			

Table 3b. Fresh biomass and species composition for macrophytes in Upper Newport Bay on 26 August 2002. The distance (dist) is distance in km from the estuary mouth; values for three replicates (a-c) and the mean are given in kg/m^2 fresh weight. The percentage composition of the dominant macroalgae in each replicate is shown as a percentage of the total (U = *Ulva*, E = *Enteromorpha*, C = *Centrocerus*).								
Stn #	Dist.	Rep A	Rep B	Rep C	Mean	Rep A	Rep B	Rep C
2	5.8	0	0	0	0			
4	6.6	0	0	0	0			
7	7.4	2.41	2.13	2.70	2.41	100% C	100% C	100% C
9	8.2	2.39	2.26	2.91	2.53	100% C	100% C	100% C
13	9.1	0.17	0.17	0.12	0.156	100% E	100% E	100% E
16	9.2	2.37	2.38	2.46	2.40	15%U, 15%E, 70%C	15%U, 15%E, 70%C	10%U, 10%E, 80%C
19	10.2	1.17	1.30	0.48	0.98	100% U	100% U	100% U
24	10.8	0.30	0.18	0.33.	0.27	10%U, 90%E	10%U, 90%E	10%U, 90%E
Mean					**1.09**			

NUTRIENT CONTENT

The nutritional status of animals and plants can be determined in various ways. In aquatic sciences the percentage of nitrogen or phosphorus and the ratio of the two had often been used. When fully replete, the typical cell contains up to 5% N and 0.3% P as a percentage of the dry weight. Seaweeds and many wetlands plants such a cattails tend to contain less nitrogen and phosphorus (N ~ 2.7%; P ~ 0.25%). Some idea of how "well fed" the algae are and which nutrient limits their growth can be gained from examination of their cellular % N or P relative to more general levels and to the N:P ratios. Values below roughly 10:1 indicate N limitation; values above 10:1 show phosphorus limitation.

The main nuisance form *Ulva* collected in July 2002 contained an average to low percentage of nitrogen but was somewhat richer in phosphorus (2.6% N, 0.45% P, Table 4). The resulting N:P of 5.6:1 was similar to past years and indicated a nitrogen shortage for this species. It is logical to ascribe the pronounced decline in *Ulva* to the efforts made to reduce nitrate in San Diego Creek. *Enteromorpha* was quite low in nitrogen and phosphorus in July (2.1 % N, 0.21% P) but somewhat richer the next month (90% *Enteromorpha* 3.4% N and 0.35% P, Table 3). However, in both cases the N:P ratio was between 9.7:1 and 10:1 indicating no relative shortage of either of theses two main growth supporting element. The small brown seaweed *Centroceras* was most common in the central section and had a higher nitrogen content with the lowest N:P values indicating that its abundance was partially controlled by other factors. An August sample of pure (3% N, 0.56% P; N:P = 5.3:1) and 70% *Centroceras* (4.3% N, 0.5% P; N:P = 8.6) indicated a more nutrient-rich algae with a slight shortage of nitrogen relative to phosphorus.

Although the and the N:P ratio and the percentage dry weights of nitrogen and phosphorus in algae indicate potential nutrient shortages in the environment, some other factors need to be considered. Phosphorus can be stored in large amounts in algae as non-toxic storage granules. In contrast, there is no similar storage system for nitrogen so the percentage-N is a more accurate reflection of the local availability of nitrate and ammonia. Thus the greater amounts of nitrogen in August in the two species sampled reflect a more available source. In August *Enteromorpha* contained 3.4% N and *Centroceras* 4.3% N (Table 4). Possibly the higher nitrogen availability was the cause of the bloom of *Centroceras* in August.

Table 4. Nitrogen and phosphorus contents of the seaweeds in Upper Newport Bay in 2002. Values are expressed as a percentage of dry weight.

Species	**% Species**	**Date**	**% N**	**%P**	**N:P ratio**	**Site**
Ulva	95	July	2.6	0.45	5.6:1	16
Mean	**95**		**2.6**	**0.45**	**5.6:1**	
Enteromorpha	90	July	2.1	0.21	10:1	9
Enteromorpha	90	August	3.4	0.35	9.7:1	24
Mean	**90**		**2.8**	**0.28**	**9.8:1**	
Centroceras	100	August	3.0	0.56	5.3:1	9
Centroceras	70	August	4.3	0.49	8.8:1	16
Mean	**85**		**3.8**	**0.5**	**7:1**	

Possible spatial effects on nuisance seaweed biomass if San Diego Creek is the main source of nitrate and algal stimulation

Upper Newport Bay can be divided into three regions or basins separated by relatively narrow channels. The lowest N:P ratios were found at stations 16 and 9 which are located in the central region of the Upper Newport Bay away from the inflow of San Diego Creek, which is suspected main source of nitrogen. Nuisance seaweed has vanished from the lower end of the estuary furthest from San Diego Creek. Since the emphasis for seaweed control in the past has been on nitrate control in the watershed, the low N:P ratio shows that this strategy could be continued with the aim of further reducing nuisance seaweeds if required. In turn, the N:P ratio indicates that sediments are not an important source of nitrogen for the seaweeds in summer. Since sediment-N is regulated under the total nitrogen winter flow TMDL, this target may need to be refined.

DISCUSSION

With the exception of the dredging year of 1999, the annual average macroalgae midsummer biomass in Upper Newport Bay has fallen steadily at about 0.2 kg/m^2 since 1996 (Fig. 1). In 1996 nuisance seaweeds were extremely dense (1.8 kg/m^2), equivalent to about 20,000 ug/L of suspended chlorophyll *a* (a typical desirable chlorophyll value would be < 25 ug/L). By 2001 the excessive eutrophication trend had been reversed and seaweed abundance had halved to 0.76 kg/m^2. The 2002 data show a continuation of much lower nuisance seaweed to only 0.3 kg/m^2 but changes in the algal species composition required adjustment to the data presentation.

If the 2002 data is used to interpolate a similar time to most other collections (here the mean of July and August), then the trend of the last 7 years is followed exactly and the value in 2002 was 0.61 kg/m^2 (34% of 1996 value). If the value for August 2002 is used alone, there was an upward trend to 1.09 kg/m^2, or approximately the value of three years before and only 61% of the 1996 value. In either case the seaweed biomass is much reduced.

However, by 2002 when the nuisance biomass had been reduced considerably, a more representative and informative method may be to separate out the nuisance and other more beneficial species in the estuary. Until 2002, the non-nuisance species, represented by the small brown algae *Centroceras*, had been minor components of the biomass. The results show a continued and steady downward trend in nuisance seaweed biomass such that the 2002 biomass of *Ulva* and *Enteromorpha* combined represent only 17% of the amount of these forms in 1996.

It is a characteristic of the intertidal seaweeds that they are distributed erratically within sites and between sites. Such high variation renders difficult the demonstration of statistical significance over time. Only the combination of collections at many sites can improve the power of the collections to give significant results and the amount of time available to the County of Orange PF & RD was insufficient for such massive collections. In addition, the amount of daylight time at the low tides needed for collection thought the entire Upper Newport Bay is restricted by natural solar and lunar cycles. Thus, demonstrating statistical significance requires time, in this case about 6 years of collections, that now show that the large decline in nuisance biomass by about 80% measured in 2002 is also significantly different from the baseline collections in 1996. Similar long delays in demonstrating statistical significance in environmental change has been reported elsewhere. For example, it required almost 11 years before Professor Charles Goldman was able to show a statistically significant decline in the clarity of Lake Tahoe. Again the high seasonal and spatial variation in the large lake obscured the trend, just as the similar spatial variability of seaweeds in Upper Newport Bay muted the downward trends.

FUTURE WORK

The collections by Orange County and others have now firmly established the decline of nuisance seaweeds in Newport Bay. The needed future work is as follows:

1. **Nutrients and nuisances weeds**. Tie the decline into the changes in nutrients, presumably, nitrate loading, to the Bay. Earlier attempts to correlate nitrate loading and seaweed were unsuccessful perhaps due to the use of annual loadings. Seaweeds are annual plants and can only use nitrate in the spring and early summer (perhaps to mid summer). Thus a seasonal loading pattern is needed. In addition, seaweeds, like all plants, do not grow on loadings (amount added per unit time) but on concentration (number of atoms present at any one time). Thus attention must be paid to the concentration of nitrate at the time and place where the nuisance seaweeds are most abundant and where they have forsaken their old habitat. A survey of nitrate in the estuary in late spring would be valuable but must use method that have a much detction level (~ 10-30ug/L as N) than past surveys (~ 0.5 mg/L)
2. **Relationship to beneficial use impairment**. The two most obvious reasons for the nuisance caused by the excessive growths of seaweeds are visual impairment and reduction in dissolved oxygen (DO) caused by seaweed respiration at night during low tides. The visual impairment is apparently gone since seaweeds are no longer common, even on the mud flats they most favor. The low DO, discovered by IRWD was only apparent using continuous recording Hydrolab meters placed at three sites in the channels for several months spanning the algal growth season. This experiment should be repeated.
3. **Publication of the results**. Few successful restorations get widespread publicity despite the need for others to learn from the long-term and costly efforts by many agencies and individuals. It is recommended that the series of reports now present be incorporated into a final report based on the 2003 season (unless some unforeseen change occurs).

AUTHORS, TEAM MEMBERS AND ANALYTICAL SERVICES

This report was prepared by Alex J. Horne, Ph.D. (Alex Horne Associates) with assistance in data analysis and figure preparation from Marcie Commins, Ph.D. (Commins Consulting). Early design and field sampling was conducted by Professor Alex Horne, James C. Roth, Ph.D. and Marcie Commins Ph.D. together with graduate students from the Ecological Engineering Group within the Department of Civil and Environmental Engineering at the University of California, Berkeley as part of their graduate training. Since 1999 collection have been increasingly made by the Orange County Public Facilities & Resources Department (especially Mary Brill and Matt Tucker). In 2000 Orange County PF& RD took over the collection and treatment of the seaweeds. Associated Laboratories, Orange, CA carried out analyses of nitrogen and phosphorus content of the seaweeds.

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Appendices #1; Seaweed collection data for July and August 2002. Collections were also made in February and March 2002 but no seaweeds were seen.

Appendix table 1. Base data for samples of macroalgae in Upper Newport Bay in July 2002
Samples were collected in the moring ending around noon.

- Sample #		%Ulva	Enter	Brow	Wet Weight (g)	ww kg	Station	Dry Weight (g)	Total N (mg/Kg)	Total P (mg/Kg)	Notes	Mass/species (kg/m2) Ulva	Entero	Cero
2-1						0.000					No Algae			
2-2						0.000					No Algae			
2-3	3					0.000	0				No Algae			
4-1	1					0.000					No Algae			
4-2	2					0.000					No Algae			
4-3	3					0.000	0.0				No Algae			
7-1	1					0.000					No Algae			
7-2	2					0.000					No Algae			
7-3	3					0.000	0.0				No Algae			
9-1	1	10%	90%		12.97	0.102		Submitted	2,070	211		0.0102	0.0922	
9-2	2	70%	30%		2.29	0.018		0.52				0.0127	0.0054	
9-3	3					0.000	0.040				No Algae	0	0	0
13-1	1	35%	65%		219.82	1.737		26.93				0.6078	1.1288	
13-2	2	20%	80%		54.84	0.433		14.81				0.0866	0.3466	
13-3	3	50%	50%		30.58	0.242	0.804	9.18				0.1208	0.1208	
16-1	1	20%	80%		0.77	0.006		0.14				0.0012	0.0049	
16-2	2	95%	5%		3.25	0.026		Submitted	2,640	451		0.0244	0.0013	
16-3	3	0%	100%		0.39	0.003	0.012	0.13				0	0.0031	
19-1	1	97%	2%	1%	5.62	0.044		1.49				0.0431	0.0009	0.000444
19-2	2	98%	2%		2.52	0.020		0.73				0.0195	0.0004	0
19-3	3	95%	5%		8.69	0.069	0.044	1.51				0.0652	0.0034	0
24-1	1										Submerged			
24-2	2										Submerged			
24-3	3										Submerged			
overall average							0.13					0.08263	0.14231	0.00004

Note, the % of seaweed for station 13-1 were not given and was estimated as the average of 13-2 and 13-3

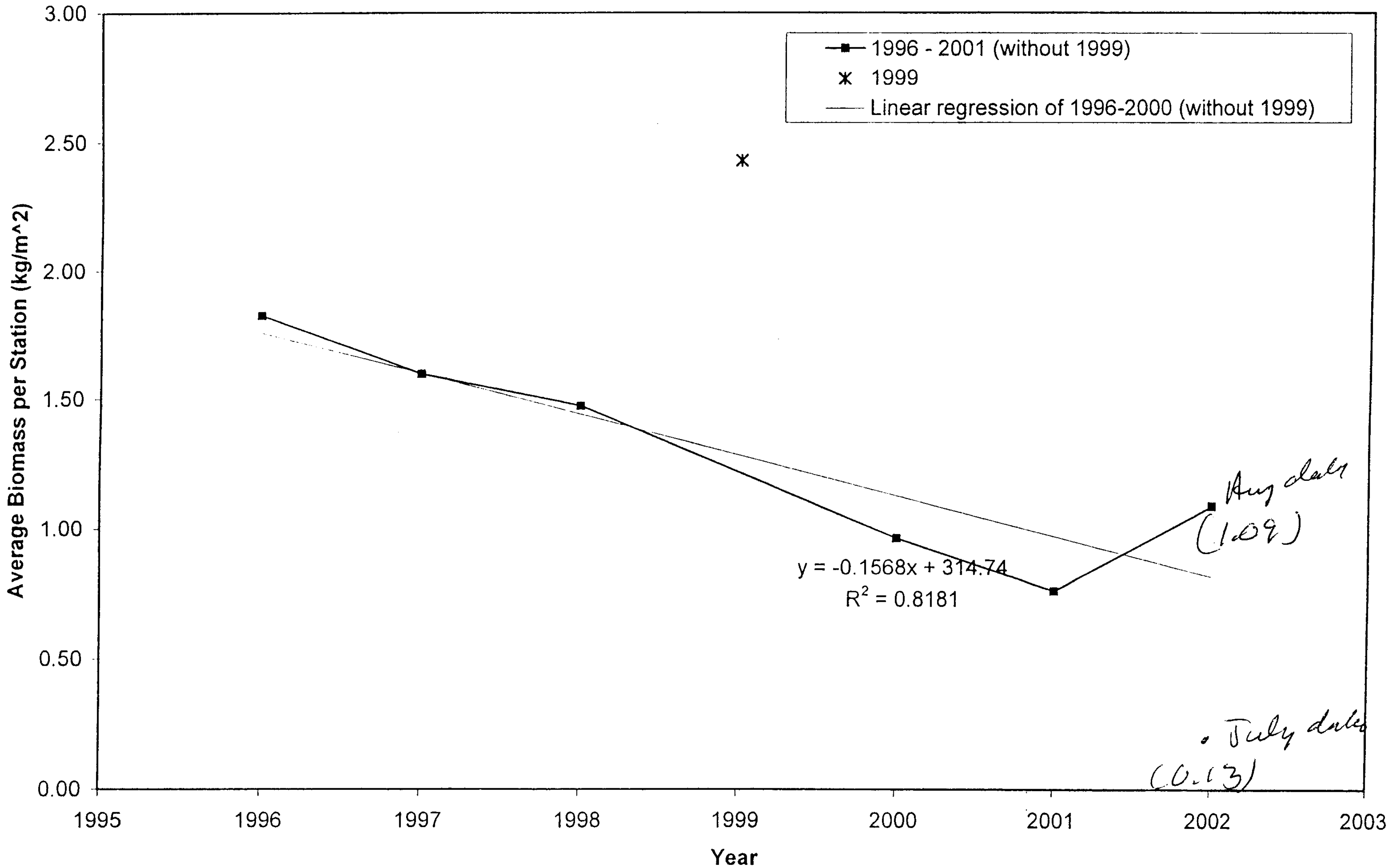
Appendix Table 2. Base data for samples of macroalgae in Upper Newport Bay in August 2002.
Sample were collected in the morning between 7 and 10 am.

Site - Sample #	%Ulva	Enter	%Brow	Weight (g)	ww kg/	Station	Weight (g)	(mg/Kg)	(mg/Kg)	Notes	mass/spp kg/m2 Ulva	Entero	Cero
2-1				0						No Algae			
2-2				0						No Algae			
2-3				0		0				No Algae			
4-1				0						No Algae			
4-2				0						No Algae			
4-3				0		0				No Algae			
7-1			100%	304.52	2.4057		113.40				0.000	0.000	2.406
7-2			100%	269.30	2.1275		92.01				0.000	0.000	2.127
7-3			100%	341.85	2.7006	2.411	145.44				0.000	0.000	2.701
9-1			100%	302.87	2.3927		105.78				0.000	0.000	2.393
9-2			100%	286.40	2.2626		98.34				0.000	0.000	2.263
9-3			100%	368.97	2.9149	2.523	bmitted	2,980	559	WR 5016	0.000	0.000	2.915
13-1		100%		21.73	0.1717		4.29				0.000	0.172	0.000
13-2		100%		21.92	0.1732		6.25				0.000	0.173	0.000
13-3		100%		15.68	0.1239	0.156	5.89				0.000	0.124	0.000
16-1	15%	15%	70%	300.16	2.3713		117.18				0.356	0.356	1.660
16-2	15%	15%	70%	301.17	2.3792		Submitted	4,300	492	WR 5016	0.357	0.357	1.665
16-3	10%	10%	80%	311.69	2.4624	2.404	84.45				0.246	0.246	1.970
19-1	100%			147.74	1.1671		27.70				1.167	0.000	0.000
19-2	100%			164.86	1.3024		36.64				1.302	0.000	0.000
19-3	100%			60.56	0.4784	0.983	8.58				0.478	0.000	0.000
24-1	10%	90%		38.25	0.3022		7.40				0.030	0.272	0.000
24-2	10%	90%		22.31	0.1762		2.99				0.018	0.159	0.000
24-3	10%	90%		42.22	0.3335	0.271	bmitted	3,350	345	WR 5016	0.033	0.300	0.000
overall average						**1.0936**					**0.222**	**0.120**	**1.117**

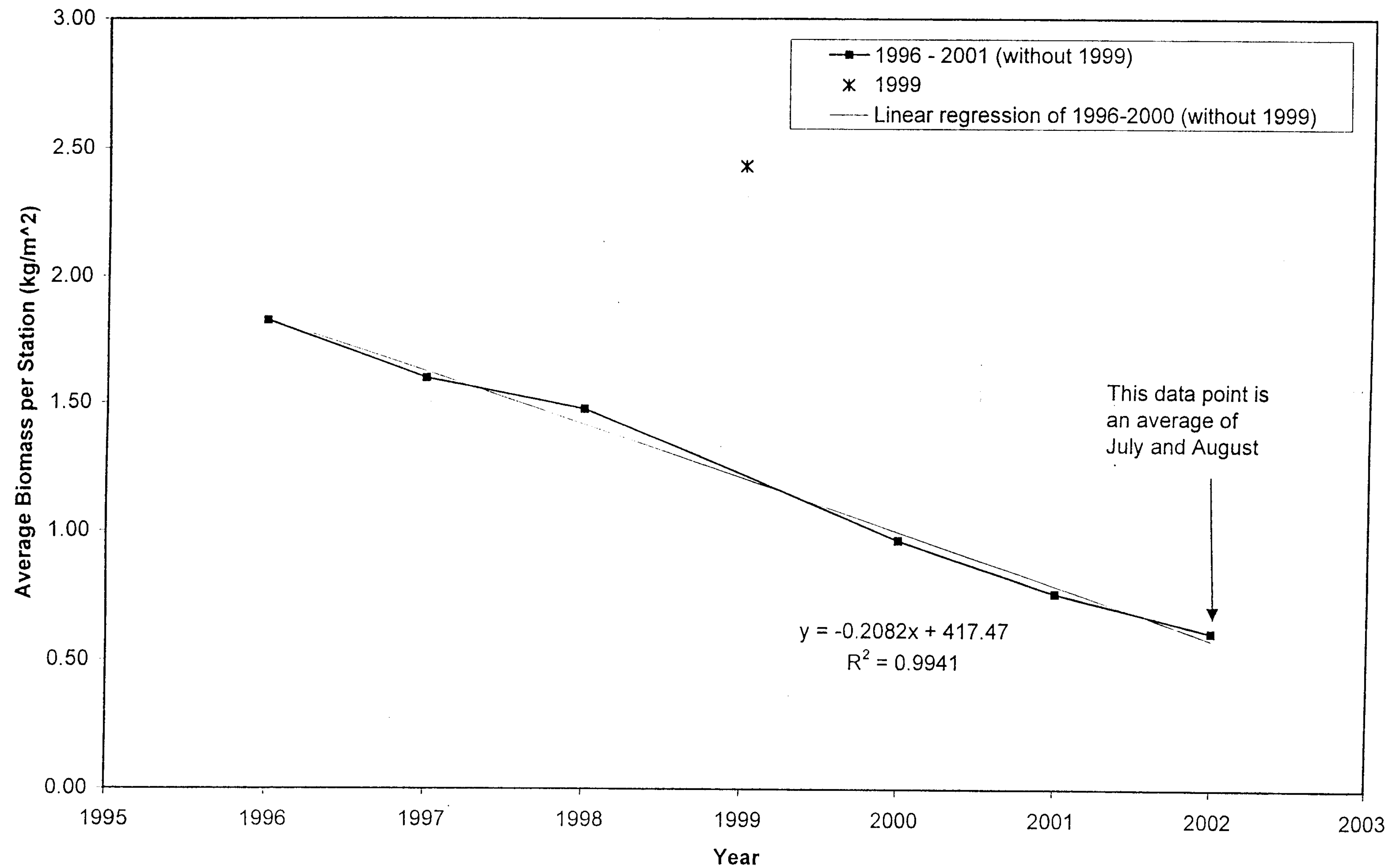
Excluding brown algae at stations 7-9 and most of 16 (use 27% of biomass or
Station

Appendices #2; Variation in seaweed biomass plotted in various ways (including the 1999 dredging year, with and without averaging the mid-July and late-August 2002 data to assist comparison with previous years when collection were made in late July.

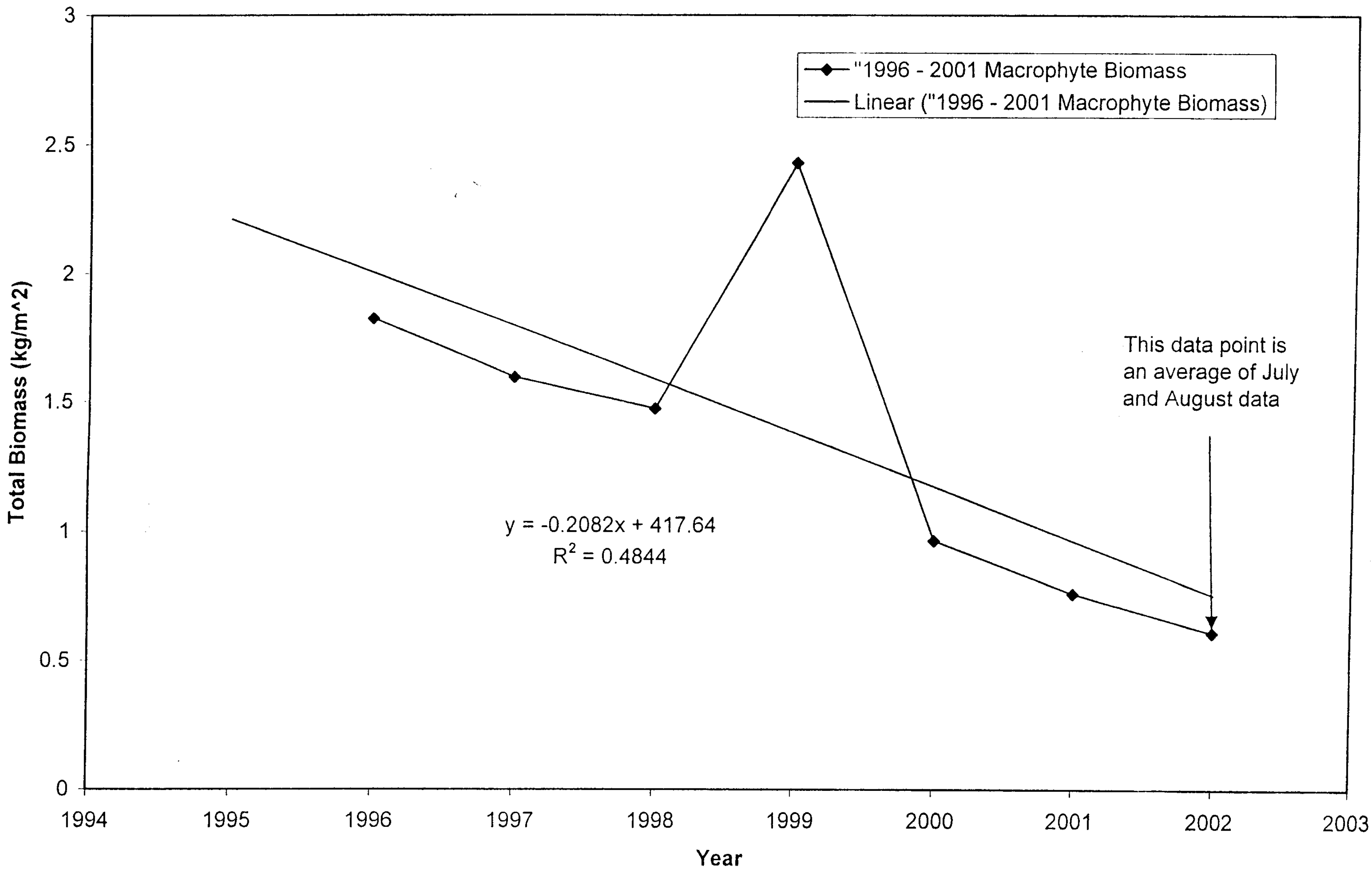
Newport Macrophytes (without 1999)



Newport Macrophytes (without 1999)



Newport Macrophytes (including 1999)



Nuisance seaweed in Upper Newport Bay, 1996-2002