Nuisance algal blooms in coastal waters: some lessons and experiences from Noosa.

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ABSTRACT

Worldwide, algal blooms in coastal waters are becoming more frequent, intense and last longer. Dense accumulations of the brown algae *Hincksia sordida* have repeatedly occurred in the surf zone of Laguna Bay in Noosa. The beaches of Laguna Bay rank amongst Australia's iconic tourism destinations, and the algae severely impact on the local tourism. Thus, it is economically vital to identify factors which favour bloom development, and, conversely, promote bloom break-down and dispersion. Despite the economic impacts of blooms, there are no standardised algal reporting programs which impedes the development of informed management responses. Analyses of bloom dynamics (e.g. bloom duration, time of development, intensity etc), thus rely on semi-quantitative observations and use "local knowledge". Nevertheless, they indicate that blooms arrived earlier, lasted longer and were more intense in recent years. Importantly, they also show that *Hincksia* blooms are not a local and recent phenomenon, but extend at least to Fraser Island and for several decades into the 60s. Local knowledge also suggests that Northerly winds coincide with the on-set of blooms, and that excess nutrients are one of the causes of blooms. Yet, we found no consistent match between wind regimes and the occurrence of blooms, but this lack of correlation may not be robust due the lack of standardised algal reporting. Similarly, in SE-Queensland, regular nutrient monitoring does not extend beyond the estuaries, making testing of the frequently mentioned "nutrient enrichment hypothesis" virtually impossible for marine waters

INTRODUCTION

Drifting masses of bloom-forming macroalgae are not uncommon in coastal seas where they typically accumulate in shallow, low-energy settings such as bays, estuaries, and harbours or are advected onshore by tides and currents (Valiela, McClelland et al. 1997; Berglund, Mattila et al. 2003). However, dense and persistent macroalgal blooms can cause considerable economic damage when they diminish the value of beaches and nearshore waters for human recreation and tourism (Hoagland, Anderson et al. 2002). This is the case for blooms of the brown algae *Hincksia sordida* (Harvey) Silva (Ectocarpales, Phaeophyta) on the subtropical east Australian coast (Phillips 2006). At Noosa unattached thalli of the algae have formed large masses in the surf zone of popular tourist beaches and algal mats have blanketed the shore when the tide receded with considerable economic repercussions for the local economy (Phillips 2006).

Management and mitigation of these blooms has therefore become a critical, and at times highly political, issue. The development of effective management interventions is, however, impeded by a lack of knowledge about the phenology of the blooms and their likely causes. What triggers the blooms at this locality has not been established with confidence, and key attributes of the bloom events (e.g. time of onset, geographic extent, historical records, etc) remain unquantified. Thus, the local government authority charged with managing and mitigating the blooms requires defensible answers to, relatively simple, questions such as: i) "what is the geographic distribution of the blooms?" (i.e. local vs. regional problem), ii) "have blooms become more severe and do they last longer in recent years"? iii) "are there climatic and oceanographic factors which coincide with bloom formation?"

METHODS

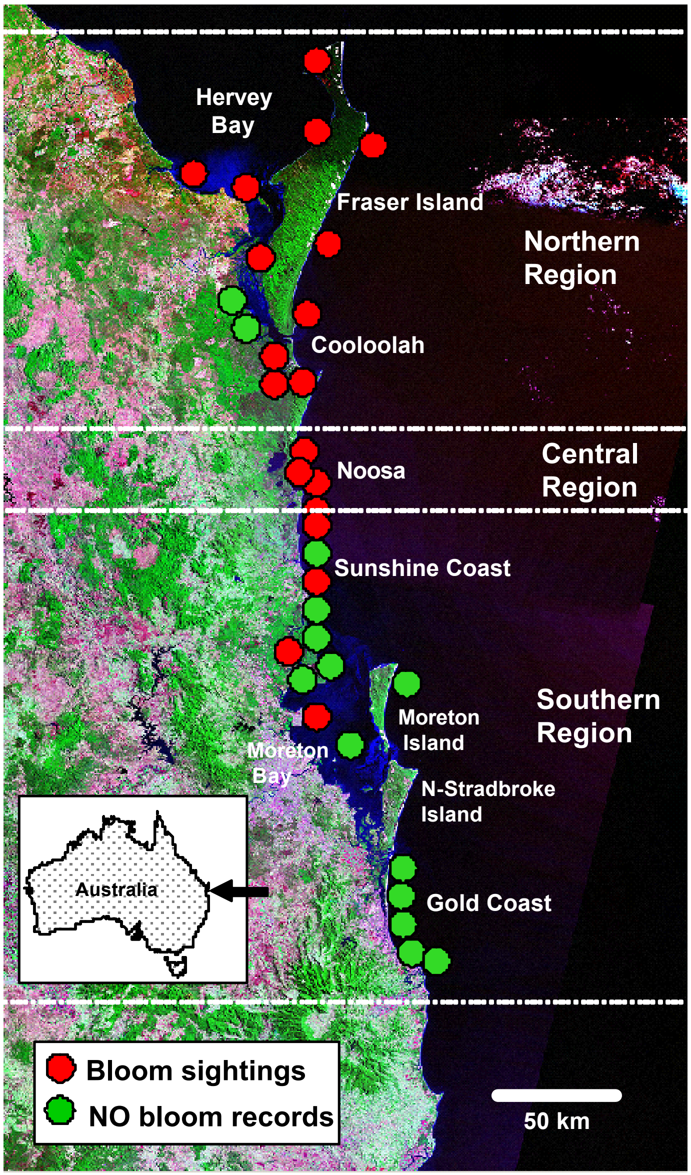

Fig. 1 Geographic distribution of bloom sightings of brown algae that were likely to have been *Hincksia sordida* in Southern Queensland, Australia.

We obtained information on key properties of algal blooms and their possible causes by conducting structured interviews. Because there was no formal, consistent and continuous recording of bloom events, oral reports by long-term residents are the only available source of information for the environmental history of the site and bloom events (see also Robertson, Nicholset al. 2000; Robertson and McGee 2003). A total of 61 persons were interviewed in February 2005. Included in the survey were Local Council officers (23%), National Park Rangers (18%), members of volunteer organizations (coastguard, environmental, ratepayers - 10%), amateur fishermen (3%), and persons operating aquatic (35%) or other businesses (11%). Aquatic businesses included commercial fishermen, water-sports instructors, equipment hire firm s, and water-based tours.

More than 80% of the respondents had more than 10 years experience with local conditions, over half of the respondents (54%) had more than 20 years of experience in the area, 30% of people interviewed could provide observations that span over 30 years in the local area, and 8% of respondents stated 45 years experience. One-third of all respondents (33%) visited a beach daily, with a further 51% visiting a beach at least once per week. Respondents were asked to provide a relative, qualitative ranking of the severity of the blooms. 'Severity' was mainly related to the volume of algae and the area of beach the algal bloom covered. Thus, the severity rating scale ranged from 1 (mild with sparse algae in the water and/or covering a small area of the beach) to 5 (very dense algae that occupied extensive sections of the beach and/or the surf zone).

KEY FINDINGS

Geographic Distribution of Bloom Sightings. A total of 541 records of brown algal bloom sightings were obtained through the interviews, of which 436 (81%) were for beaches and near-shore marine waters and 105 (19%) for estuaries (Table 1). The number of years for which respondents could provide observations on coastal waters was not related to the number of blooms they reported ($r_s = 0.07$, $P = 0.59$, $n = 61$). This de-coupling between observation period and bloom numbers may indicate that blooms are a relatively recent phenomenon; it could, however, equally occur due to a decrease in long term memory of bloom events. After correction for experience and observation effort, significantly fewer blooms were reported from beaches and near shore, marine waters south of Noosa (Figs. 2&3). By contrast, the frequency of bloom records was similar for Noosa and areas further north (Figs. 2&3).

Table 1 Number of algal bloom records in each of three regions. Also reported is feedback from survey respondents that affirmatively stated that they observed NO *Hincksia sordida* blooms in a particular region.

	# Bloom Sightings			***NO Bloom Sightings***		
Region	**Beaches**	**Estuaries**	**Total**	***Beaches***	***Estuaries***	***Total***
1. Northern Region						
1.1. Hervey Bay & Sandy Straits	9	15	24	*2*	*4*	*6*
1.2. Fraser Island	97	0	97	*0*	*0*	*0*
1.3 Cooloola (Inskip point to North Shore)	35	0	35	*0*	*0*	*0*
Subtotal North	**141**	**15**	**156**	***2***	***4***	***6***
2. Central – Noosa	**220**	**90**	**310**	***0***	***0***	***0***
3. Southern Region						
3.1. Sunshine Coast	54	0	54	*11*	*2*	*13*
3.2. Moreton Bay & Islands	8	0	8	*4*	*3*	*7*
3.3. Gold Coast	13	0	13	*18*	*3*	*21*
Subtotal South	**75**	**0**	**75**	***33***	***8***	***41***
TOTAL all Regions	**436**	**105**	**541**	***35***	***12***	***47***

The number of blooms reported was not correlated with how often observers visit beaches and/or nearshore marine waters ($r_s = 0.06$, $P = 0.63$, $n = 61$). This lack of a relationship between observation frequency and bloom returns suggests that blooms are prominent features and last long enough to be seen by a variety of people, irrespective of how often they visit the beach.

Long-term trends in bloom sightings Based on this survey, *Hincksia sordida* blooms have occurred in Southern Queensland for more than 40 years (and more regularly over the past 25 years), with sightings dating back to 1965. Irrespective of the 'historical limitations' arising from personal experiences of the survey respondents, it appears that blooms are not a recent phenomenon of the last couple of years only, but are likely to have occurred in the coastal waters of Southern Queensland for at least several decades

Seasonality and severity of blooms. To determine the seasonal pattern of bloom occurrence, we asked survey participants to recall the month and year when they commonly saw blooms appear, and how long the blooms lasted. There was substantial variation in the seasonal timing of bloom occurrence, with blooms occurring later in the year with increasing latitude. In regions north of Noosa, the blooms appeared in the early austral winter (June/July) and lasted until the end of the austral summer (February to March of the following year. At Noosa, the 'bloom season' appears to be shorter, starting in September/October and lasting until December/January. Further south, blooms developed even later in the year (November) and usually dispersed 1-2 months later.

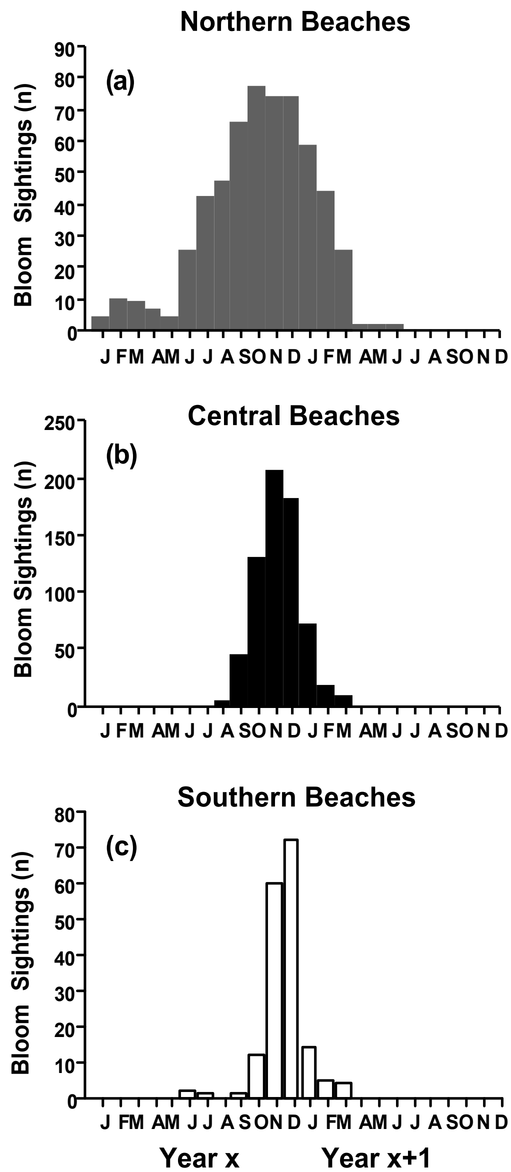

Fig. 2 Seasonality of algal blooms in each of three regions. (because many blooms straddle calendar years - occurring often from spring to late summer – the temporal distribution is plotted from the first calendar year when a bloom developed (year x) to the following calendar year (year x+1) when the bloom dispersed).

Not only do the blooms arrive earlier on the beaches to the North of Noosa, but they also remain there for significantly longer. The average time for which blooms remained on the Northern Beaches was 6 months compared with 3 months for Noosa blooms. The few blooms reported from the South were significantly shorter in duration than both the other regions, lasting on average 2 months and 1 week.

The severity of blooms differed substantially between the three regions (ANOVA, $F = 12.73$, $P < 0.001$), with the average bloom severity ranked higher in the Northern sections (3.86) than Noosa (3.21) or the southern sections (2.94). Most respondents judged the blooms to have become more severe in recent years at Noosa (Fig. 5c).

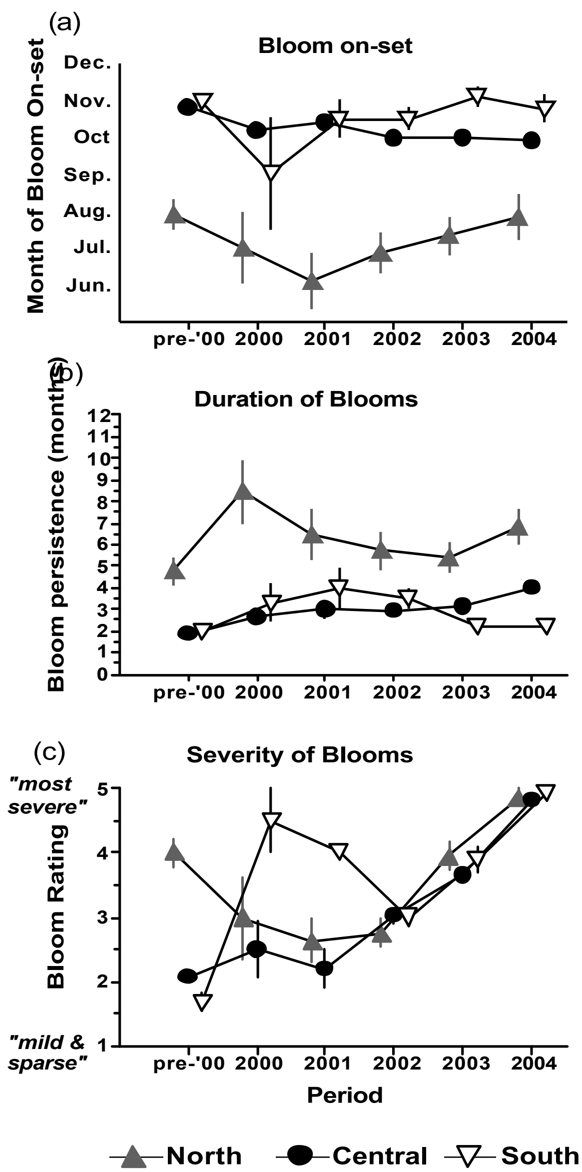

Fig. 3 Temporal trends in a) the time of bloom arrival on beaches and in near shore, marine waters, b) the duration of blooms, and c) their severity (severity is a qualitative rating by respondents, ranging from 1 ~ 'mild and sparse' to 5 ~ 'sustained and dense').

Factors coinciding with bloom development and dispersal. Survey participants were also asked to list any factors or conditions that they have observed to coincide with the bloom arriving. The returns can be broadly grouped into a narrow band of conditions, with more than half (55%) of all respondents identifying northerly winds as the key contributing factor for algal blooms to develop. A further 13% listed rainfall and temperature, with 'warm weather' being the most prevalent in this category. Small swells and surf waves were mentioned by 18% of respondents to coincide with the arrival of algal blooms.

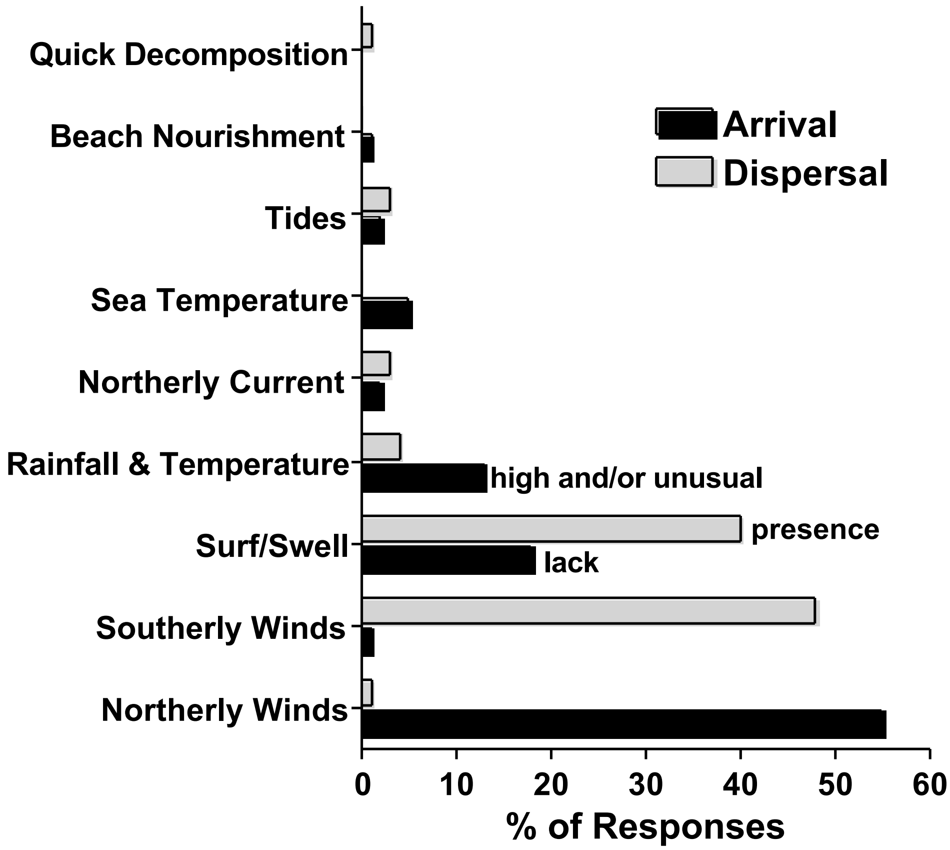

Fig 4 Summary plot of factors and conditions put forward to coincide with the arrival/development of blooms (solid) and the dispersal/departure of blooms (grey bars).

Of all the factors that were thought to contribute to the dispersal of algal blooms, almost half (49%) of responses cited winds from the south. This is almost an exact juxtaposition to the 55% of responses that listed northerly winds blowing when blooms arrive. The presence of swell and surf was cited with almost equal frequency (44%), with blooms seen to disperse around the same time that swell and surf increased in height. There were only few nominations that did not relate to southerly winds or swell/surf and these included northerly currents, tidal advection and decomposition of the algae.

Putative cause(s) of blooms. In addition to requesting information on factual observations by survey participants (e.g. arrival and duration of blooms, weather conditions during bloom development, etc.), an open question was included that was designed to gauge the opinion of respondents about the underlying causes of blooms. A diverse range of opinions about the causes of the blooms was offered (Table 4), compared with a much narrower band of observations about factors which coincided with bloom arrival and departure. It must be stressed that 'causes' reported by participants in the interviews have not been critically examined, independently tested or reviewed in any form – they essentially represent opinions only.

Nevertheless, the responses are highly informative and fall into four broad categories: (1) Weather was cited most often as being related to bloom formation (46 responses), identifying warmer air- and sea-temperatures as possible causes. (2) Nutrients are the second most frequently cited 'cause' of the blooms (36 responses). A wide range of opinions about the sources of putatively elevated nutrients was offered, including unspecified anthropogenic sources, changed coastal land-uses, canal estates, and *Trichodesmium* (Table 2). (3) Natural causes have been put forward 12 times without explicit links to human activities. (4) Man-made causes (other than nutrients), citing either that beach nourishment is linked to blooms or categorically stating that it is not (Table 2).

Table 2 Factors cited by respondents as possible causes contributing to the formation of algal blooms.

	n	%
'Process of Nature'	**12**	**11%**
'Nutrient-Related'	**36**	**33%**
Increased nutrients (general anthropogenic sources)	18	
Coastal land-use practices to the North	7	
Nutrients from waterfront properties/lakes	5	
Algae arrives attached to weed which provides nutrients	2	
Chelated iron related to pumping river sediments	1	
Coral spawn (nutrients)	1	
Northern nutrients combine with local offshore algae	1	
Laguna Bay provides optimal environment for algae growth	1	
'Weather & Landscape Factors'	**46**	**42%**
Warm water & high temperatures	12	
Global warming	9	
Changes in weather patterns	9	
North-facing beach acts as a trap for algae	7	
Lack of big flood	3	
Drought conditions and subsequent river flushing	2	
Dry winters	1	
High salinity	1	
NE winds a factor in transport	1	
Lack of rainfall and swell to interrupt growth cycle.	1	
"Beach Nourishment"	**2**	**2%**
"NOT a consequence of beach nourishment"	**2**	**2%**
'Changes to hydrodynamics of river'	**6**	**6%**
'NOT a consequence of changes to River'	**5**	**5%**
Total Responses	109	(100%)

TAKE HOM E MESSAGES

1. Worldwide, algal blooms in coastal waters are becoming more frequent, intense and last longer. Between 2000 and 2005, dense accumulations of the brown algae *Hincksia sordida* repeatedly reduced the aesthetic value of Noosa beaches with a consequent negative effect upon the local economy.
2. Investigation into the cause of the bloom s and the subsequent development of management solutions would have benefitted from formal systems to record the timing of bloom formation and dispersal. Such algal monitoring also needs to measures possible drivers such as nutrient concentrations in marine waters.
3. Targeted social surveys (i.e. structured interviews) have been shown to proved to be a useful method of obtaining information on this other issues in coastal management. We found that it provided knowledge not available from other approaches. Equally, it is useful in generating hypotheses which need to be carefully tested by more formal, scientific methods.
4. A combination of structured interviews to harness the wealth of local ecological knowledge and bio-physical, scientific methods offer synergies in enhancing management outcomes for algae and other coastal issues.

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