# NUTRIENT STATUS AND OTHER SOIL FACTORS AFFECTING MANGROVE PRODUCTIVITY IN NORTH-EAST AUSTRALIA

**KEVIN G. BOTO**

**Australian Institute of Marine Science**
**P.M.B. 3 Townsville M.S.O.**
**Queensland 4810**

In the inaugural issue of this journal, Field (1981) outlined the necessity for fundamental research directed towards the informed management of mangrove forest resources in the Australasian region. Two important topics to be considered in this context are the measurement of mangrove forest primary productivity, especially over large spatial scales, and the elucidation of environmental factors influencing productivity.

The purpose of this paper is to discuss the problems involved in these aspects of mangrove research and the approaches adopted by us towards solving these problems. Results obtained to date in our research program are summarised with emphasis on emerging concepts concerning the effects of soil properties on mangrove productivity.

## PRODUCTIVITY ESTIMATES — PROBLEMS AND APPROACHES

Measurement of net primary production on a whole-forest scale is not solely a problem for mangrove researchers. Obviously, those concerned with rain forest studies or monitoring commercial pine forests would also prefer production estimates over a similarly large scale. In terrestrial systems, large scale gas exchange systems and/or the use of micro-climatology measurements are feasible, albeit both approaches are extremely technically demanding and, in many cases, logistically difficult. When one considers the mangrove environment in the northern Australian region (see Figs. 1 and 2), where forests are generally large in area, extremely inconveniently located in remote situations and mostly characterised by dense, barely penetrable prop root formations at ground level, the logistic difficulties are multiplied enormously. Gas exchange measurements can be carried out on a reduced scale but then suffer from difficulties in the extrapolation of results to the whole canopy. Recording of litter fall has been the most generally adopted approach. However, while these data are practically useful, providing, for example, necessary baseline data for trophodynamic studies (Boto and Bunt 1981), they cannot disclose the complete magnitude of net photosynthesis and inevitably demand long periods to accumulate useful data.

For survey purposes over extensive and remote coastlines, convenient means are needed to evaluate potential net primary production. We have therefore chosen an approach (Bunt *et al.* 1979) which employs simple *in situ* measurements of light attenuation through forest canopies to firstly estimate canopy chlorophyll standing stocks, from which potential production can be estimated. This approach was based on the methods of Kirita and Hozumi (1973) applied to Japanese oak forests. The method was calibrated by extensive leaf analysis data for a large number of different mangrove species from widely varying locations.

## PRODUCTION ESTIMATES — LOCAL AND REGIONAL VARIATIONS

Since the development of the survey method, production estimates have been obtained from a number of widely separated localities in northern Australia. A more limited data set has also been obtained for the Gulf of Papua region. In practice, the accumulation of productivity data is inevitably opportunistic because of the spatial scales involved. Major limiting factors have proved to be the availability of boat time and appropriate climatic conditons. For example, if external light conditions are not constant (fluctuating cloud cover) during a visit to any given site, reliable data cannot be obtained. Nevertheless, the results that have been achieved to date are considered to be reasonably reliable estimates of potential net primary production and some interesting local and regional patterns are evident. These results are summarised briefly in Table 1. The results for the Hinchinbrook Island mangroves are shown in greater detail in the paper by Bunt *et al.* 1979, where detailed comparison with litter fall data at corresponding sites are made. It suffices here to quote the mean litter fall rate for the area, derived from 22 catchers over a 1 to 3 year period, as 12.5 kg carbon. $ha^{-1}day^{-1}$. The average potential production estimate ($P_N$) for the same sites was found to be in the order of

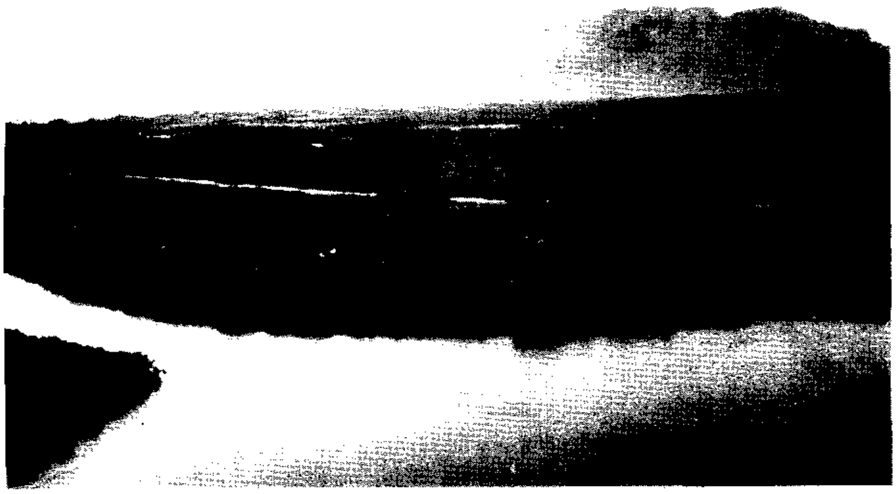

Figure 1:
An oblique aerial view of a section of the ca. 50 km² mangrove system in Missionary Bay, Hinchinbrook Islands. This system is predominantly tidally influenced and is dissected by 8 large tidal channels, some of which are visible in this photograph.

Figure 2:

A ground-level view showing the dense, almost impenetrable prop root formations in these *Rhizophora* dominated forests.

Figure 3:

Part of the ca. 400 m long 'catwalk' transect used for the more intensive studies carried out by AIMS researchers. The catwalk traverses an area between two tidal channels.

26 $kgC.ha^{-1}day^{-1}$. On the basis of a limited set of gas exchange data for this area (Andrews, Clough and Muller unpublished data), the $P_N$ value is considered to be, perhaps, a slightly low estimate. Hence, it can be seen that litter fall accounts for about ≦48% of the net primary production. In addition, comparison of the $P_N$ value with data available for other marine and terrestrial systems also shows that the mangrove production estimates are reasonable. Typical net primary production values for other systems are (in $kgC.ha^{-1}.day^{-1}$): (a) *Laminaria* spp. (Atlantic Ocean) - 33 to 55; (b) *Thalassia* spp. (Indian Ocean) - 14 to 35; (c) Oak forest (New York, U.S.A.) - 14; (d) Pine plantation (England) - 21; (e) Intensively cultivated alfalfa (U.S.A.) - 41 and (f) sugar cane - 92 (Mann and Chapman 1975).

TABLE 1: A summary of mangrove forest estimates ($P_N$ - $kgC.ha^{-1}.day^{-1}$) for various localities in northern Australia and the Gulf of Papua.

A. Hinchinbrook Island (Missionary Bay):
Total number of sites = 27
Overall range in $P_N$ = 3-38
average = 26

B. Cape York rivers: 17 sites from the Jardine, Escape Harmer, Olive, Pascoe, Nesbit, Rocky, Annie and Annan Rivers (see map - Fig. 4):
Range in $P_N$ = 11-26
mean = 19

C. North-western Australia:
2 sites near Derby, W.A.
$P_N$ = 18-23
mean = 21

D. Gulf of Papua: 6 sites in the Purari Delta near Baimuru:
Range in $P_N$ = 18-34
mean = 28

Production estimates for mangrove forests in various riverine systems along Cape York Peninsula are also summarised briefly in Table 1 (see map in Fig. 4 for site locations). Although this data set is still somewhat limited in relation to the size of this region, there is an obvious trend towards significantly lower production estimates in the Cape York region, where the mean $P_N$ over the 17 sites studies is in the order of only 19 $kgC.ha^{-1}day^{-1}$. In addition, none of the Cape York sites show $P_N$ ≧30 whereas 9 of the 27 Hinchinbrook sites have $P_N$ ≧30. The two north-western Australian sites give a mean $P_N$ = 21, comparable to the Cape York forests. For the 6 Gulf of Papua sites, (including a rain forest area for comparison), the mean $P_N$ is ca. 28, comparable to the Hinchinbrook forests.

Obviously, a good deal of further data is required, especially from the western Australian and Gulf of Papua region, before true regional averages and ranges can be obtained. Nevertheless, the presently observable trends, both in terms of local variations within the Hinchinbrook forests and the regional trends do appear to be compatible with emerging trends from our concurrent studies of soil factors.

## SOIL FACTORS INFLUENCING MANGROVE PRODUCTION

A fourteen month intensive study of temporal and spatial variations of soil factors, for the 400 m catwalk transect site at Coral Creek, Hinchinbrook Island (Fig. 3) has been recently completed (Boto and Wellington a,b in press). Here, the results can only be summarised in the briefest manner, however, the major findings to emerge from this study were:

(a) Mangrove standing crop biomass was significantly correlated with the following soil factors (averaged over 0-100 cm depth and over the fourteen month period); (i) extractable phosphorus (soil P); (ii) salinity (negative correlation) and (iii) redox potential ($E_H$), i.e. a measure of the intensity of reducing conditions in the waterlogged soils.

(b) Average soil extractable phosphate ranged from 5(±2) to 20(±4) $\mu g\ P.g^{-1}$ dry soil over the 8 transect sites within the vegetated zone. The higher soil P values were obtained at the tidal channel edge sites (low elevation) while the lower soil P values were found at the higher elevation (ca 1.4 m v. A.H.D.) areas in the middle of the transect. Soil ammonium values showed much less variation with position and ranged from 4.6 (±2.2) to 7.3 (±2.6) $\mu g\ N.g^{-1}$.

(c) A fertilisation experiment, conducted over a twelve month period, showed significant mangrove growth response to soil ammonium enrichment at the site of highest 'native' soil $NH_4$, indicating that nitrogen limitation is common to all sites. On the other hand, P limitation was indicated only for areas of low 'native' soil P (5 μg.g$^{-1}$) whereas no growth response was found in areas of higher soil P (>10 μg P.g$^{-1}$).

The variation of $P_N$ with topographic height in the Coral Creek area is shown in Figure 5. Interestingly, the $P_N$ values correlate very closely with standing crop biomass estimates and hence $P_N$ also correlates closely with soil extractable P, as is evident from the soil P-topographic height relationships shown for comparison in the same figure. The results are encouraging in that they suggest that the survey method yields productivity estimates which are sufficiently precise to measure relative changes over small spatial scales. Also, of interest, is the obvious lack of relationship between $P_N$ and soil P at the extremely low elevation sites. This is almost certainly due to the fact that inundation stress is the dominant control at these sites, i.e. these sites are almost continuously by tidal water except for very brief periods at very low tides. The soil $E_H$ values confirm this hypothesis, with levels of -180 to -200 mV being consistently measured at these sites compared to values of -120 mV (i.e. less reducing conditions developed) measured at the slightly higher elevation sites.

Preliminary surveys of soil properties in a number of Cape York rivers show a number of interesting features in comparison with the soils in the almost exclusively tidally influenced Hinchinbrook system:

(a) At virtually all sites examined to date in 6 widely spaced river systems, the soil P values were extremely low, in the order of only 0.1 to 5 μg P.g$^{-1}$.

(b) Soil ammonium levels were comparable to, and perhaps slightly greater than, those found for the Hinchinbrook soils.

(c) Much lower soil salinities and significantly less intensely reduced conditions were found in the Cape York soils, consistent with the obvious riverine influence and with the greater permeability of these generally sandy soils.

It should be stressed that these results are only preliminary in the sense that the full range of seasonal variations has not been effectively examined to date. Nevertheless, it is tempting to speculate that the generally lower production estimates obtained for the Cape York mangroves reflect the very low phosphorus status of these soils. The lower salinities and less intensely reducing conditions of these soils would tend to be beneficial although their combined effect would not appear to offset the apparently severe phosphorus limitation in these systems. Further, it is interesting that Viner (1979) has reported total soil phosphorus levels, for the Purari delta region (Gulf of Papua), in the order of 400 ppm, very similar to the total P level of the Hinchinbrook soils.

## CONCLUSIONS

Obviously, much further data need to be obtained to fully explain the influence of edaphic factors on mangrove production. In particular, more detailed information on seasonal variations in soil properties from a much larger number of sites is required. Nevertheless, the limited data presently available show many encouraging features. The productivity survey method appears to yield estimates which are compatible with litter fall measurements and data from other systems. In addition, the simultaneous correlations of the $P_N$, biomass and soil P data derived from the more intensive studies in the Hinchinbrook system imply that the method yields useful estimates of between-site variations in productivity. Finally, the preliminary results from the large scale production and soil surveys strongly indicate that soil phosphorus status is a dominant influence on mangrove primary production in northern Australia. This hypothesis is entirely consistent with the generally low phosphorus levels of Australian soils and the well established influence of this factor in terrestrial plant systems of this continent (Beadle 1953).

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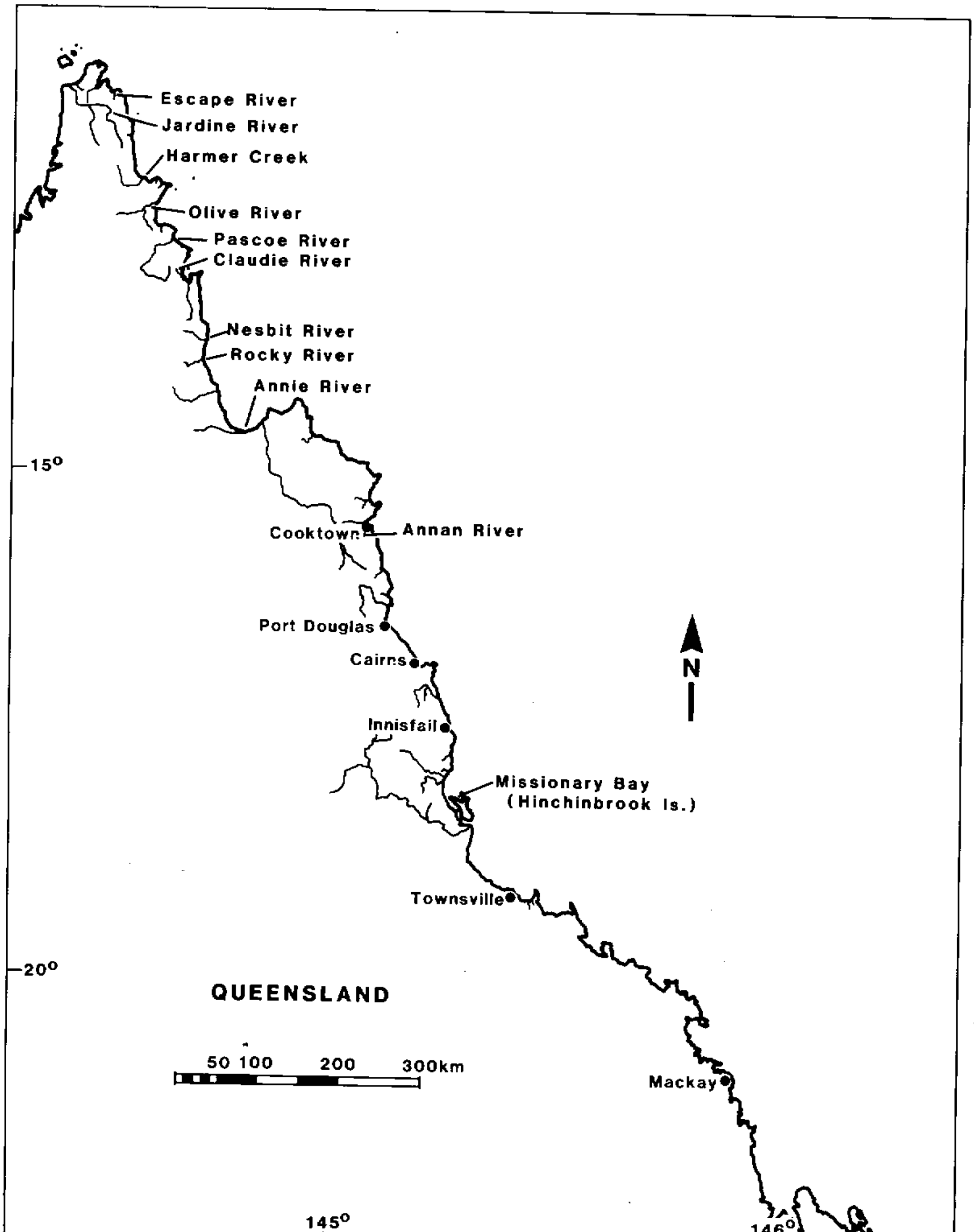


Figure 4: A map of north Queensland showing some of the remote location areas investigated as part of the AIMS mangrove program.

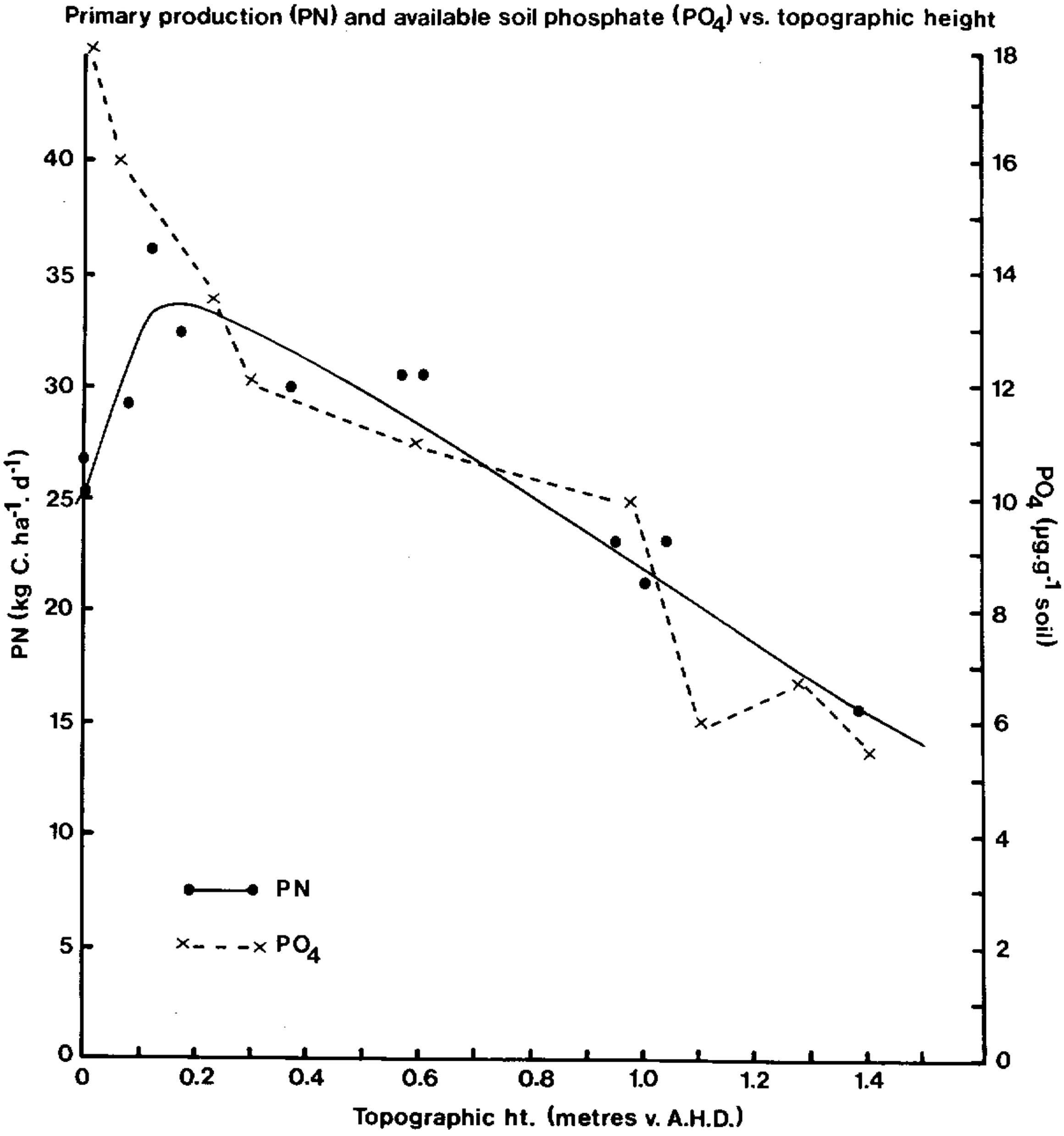


Figure 5: The variation of productivity ($P_N$ -kgC.ha$^{-1}$day$^{-1}$) with topographic height in Coral Creek, Missionary Bay. Also shown are average values of soil extractable P at the various elevations (averaged over fourteen months and for 0-100 m depth cores). Topographic height data were supplied by the Australian Government Survey Office.