Ocean dispersal modelling for propagules of pond apple (*Annona glabra* L.)

Luciano B. Mason[2], Melissa J. Setter[1], Stephen D. Setter[1], Thomas Hardy[2] and Michael F. Graham[1]
[1] Biosecurity Queensland, Department of Primary Industries and Fisheries, PO Box 20,
South Johnstone, Queensland 4859, Australia
[2] Maritime Modelling Unit, Australian Maritime College, PO Box 986 Launceston,
Tasmania 7250, Australia
Email: melissa.setter@dpi.qld.gov.au

Summary Pond apple is one of Australia's top twenty Weeds of National Significance (WoNS). It invades riparian and coastal environments with water acting as the main vector for dispersal. As seeds float and can reach the ocean, a seed tracking model driven by near surface ocean currents was used to develop maps of potential seed dispersal.

Ocean currents driven by historical wind data, tides and a synthetic East Australian Current (EAC) were computed for the Great Barrier Reef (GBR) and Gulf of Carpentaria (GoC) regions over six seasons.

Seeds were 'released' in the model from sites near the mouths of major North Queensland rivers. Most seeds reach land within three months of release, settling predominately on windward-facing locations. During calm and monsoonal conditions seeds were generally swept in a southerly direction, however movement turns northward during south easterly trade winds. As an example, seeds released in February from the Johnstone River were capable of being moved anywhere from 100 km north to 150 km south depending on prevailing conditions. Although wind driven currents are the primary mechanism influencing seed dispersal, tidal currents, EAC and other factors such as coastline orientation, release location and time also play an important role in determining dispersal patterns of pond apple seed.

In extreme events such as tropical cyclone Justin in 1997, north east coast rivers could potentially transport seed over 1300 km to the Torres Strait, Papua New Guinea and beyond.

Keywords Weeds, seed tracking, Great Barrier Reef, ocean currents.

INTRODUCTION

Pond apple is a major weed of riparian and coastal environments in the wet tropics and water appears to be its main mode of dispersal. Setter *et al.* (2008) show that seed can float and remain viable for over 12 months, in fresh and salt water. Seeds are frequently found floating near shore or beached onshore, particularly after flood events.

In this study we used modelling of ocean currents to identify locations that seeds are likely to be deposited via water. This will aid in prioritising search and control activities. Physically accessing and controlling pond apple once detected in these environments is difficult, but not impossible. There are a number of control programs currently in progress throughout northern Queensland which would directly benefit from this information.

MATERIALS AND METHODS

Modelling the movement of pond apple seed was a multi-step process that included: i) the modelling of near surface currents; ii) the tracking of seed from release to 'beaching' for release locations near the mouths of 16 Queensland rivers, and; iii) compilation of statistics on beaching locations.

The hydrodynamic model *MMUHYDRO* (Bode and Mason 1994, Bode *et al.* 1997, Bode and Mason 2005) was used to compute the near surface currents that were stored and then used to disperse particles that represent pond apple seeds. At present it is not computationally feasible to simulate the entire GBR and GoC region on a single high resolution grid. To overcome this we use a system of grids with different resolutions and extents (Figure 1). They consist of a single large but coarse grid of the GoC (9.3 km), and 17 high resolution coastal grids (555 m) nested within a large coarser GBR grid (1.85 km). These grids include almost the entire Queensland coast starting from Fraser Island and into the GoC.

In the GBR, primary influences on ocean currents are associated with forcing from the wind, tide and EAC. For the period March 1996 to April 2003, six hourly winds fields, from the Bureau of Meteorology (BOM) Limited Area Prediction System (LAPS), were used in the modelling process. The effects of the EAC and tides were introduced into the modelling system as water levels at the boundaries of the GBR and GoC grids.

PATRACK, a Lagrangian particle tracking model, was developed to compute the movement and 'beaching' location of pond apple. It uses near-surface current fields computed from the multiple grid system to seamlessly track seed as they move between grids. This capability meant that seed could be tracked anywhere in the region defined by the outlines of the GBR and GoC grids in Figure 1.

Pond apple generally drop fruit in the period from February to April but may include January and May if conditions are suitable. This period corresponds closely with the most common time for floods when pond apple may flush to sea. To represent the initial dispersal of pond apple by floods, particles were released in 10 km long lines near the mouth of 16 Queensland rivers. Each release line consisted of 101 particles and was oriented perpendicular to the coast. To encompass the complete fruit drop and flood season, releases were conducted every half hour from the start of January to the end of May. This means that 727,200 particles were released from each river in a season. Each particle was tracked till it is 'beached' or for 90 days maximum. The process was repeated for years 1997 to 2002 when winds from LAPS are available. Note that in 1997, Tropical Cyclone Justin influenced weather patterns for 17 days causing a large disturbance in the current patterns.

RESULTS

MMUHYDRO A representative snapshot of the near surface current vector fields produced by the GBR and GoC grids is shown in Figure 2. Currents east of the GBR are dominated by the EAC while near shore they are predominantly wind driven. In the Torres Strait and GoC currents are dominated by the tide (Figure 2).

Significant changes in wind (monsoon to trade winds) and EAC can have a large influence on ocean currents throughout the season when particles are released and tracked. In Figure 3, the time history of modelled shore parallel currents are plotted for a location near the Johnstone River. At short time scales the variation in currents is dominated by the tides (grey line) with some contribution from the wind, which produces the spikes in the current record. At periods of 1 to 4 weeks we see large fluctuations in currents that can be attributed to large scale changes in wind patterns. On a seasonal time scale, changes in weather patterns and the EAC cause a gradual change in the north/south tendency of the near shore currents.

PATRACK For each seed release the following output was recorded: i) start time and location; ii) end time and location, and; iii) end state defined as either 'beached', 'still floating' or 'outside domain'. This allows any combination of seed releases to be queried and analysed. For example, seed could be grouped in week lots and analysed for beaching location.

For this project, the primary analysis involved determining the beaching latitude of seeds from each river on a monthly basis and grouped into those from

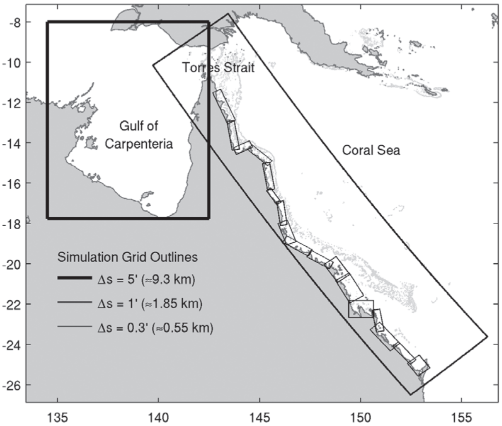

Figure 1. The outlines of the hydrodynamic grids: GoC grid (5'), GBR grid (1'), fine scale coastal grids (0.3').

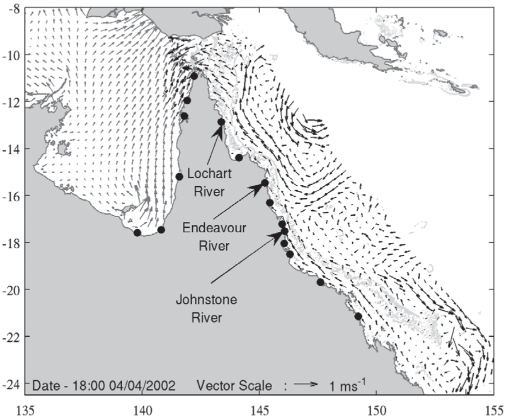

Figure 2. A snapshot of near surface currents, from the GBR (black) and GoC (grey) grids. Dots are the location of river mouths.

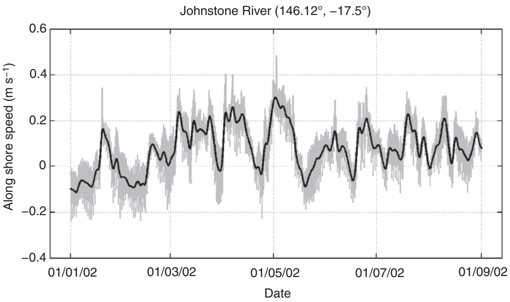

Figure 3. Time history of along shore currents 5 km from the mouth of the Johnstone River: raw currents (grey); low frequency currents (black).

1997 and years 1998–2002. Statistics derived from these groupings are shown in Table 1 for the Johnstone River.

In general, results show that most seeds are beached near the release site and well within the 90 day tracking period. For the Johnstone River 83% of seeds released during seasons 1998–2002 were beached within 31 km of the river mouth (Figure 4). However larger excursions are possible, particularly when winds are offshore.

DISCUSSION

On the Queensland east coast the south-easterly trade winds are dominant. Thus the mean offset in beaching location will tend to be skewed to the north. However, when the south-east trade winds are strong the excursion lengths can be short as the winds will tend to quickly move seeds onto beaches. The periods of monsoon winds are most likely to have a persistent offshore component. Therefore, releases from the northern rivers are more likely to experience the larger excursions because the northern parts of Australia are most affected by the monsoon winds. Results (data not shown) show that both the Lockhart and Endeavour Rivers have large excursion lengths during these periods, with the latter having the largest excursion because it is situated just south of Princess Charlotte Bay where seeds can more easily be transported into oceanic currents (EAC).

In 1997 the large cyclonic event, T.C. Justin, caused significant increases in excursion lengths, with all east coast rivers having seeds transported to the Torres Strait and PNG. In some cases seeds travelled through the Torres Strait into the GoC but remained in the northern part of the GoC.

When seeds move to Torres Strait region they either beach on an island, the PNG coastline or move north-west through the strait towards the Arafura Sea. No movement is seen down the western coast of Cape York. However, seeds released from the GoC rivers can move along the coast, particularly during monsoon winds. During the trade wind period large portions of seeds released from the west coast of Cape York can move to the west-north-west and strike the Northern Territory coast. Even with these long excursions across the gulf, most seeds beach within the 90 day tracking period, although a larger proportion are lost or remain active than for the east coast releases.

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Table 1. Mean (S.D.) offset of beaching latitude from the Johnstone River.

Month	Years	
	1997	1998–2002
Jan	−0.033 (0.303)	0.021 (0.246)
Feb	0.041 (0.236)	0.007 (0.281)
Mar	0.883 (1.462)	0.114 (0.154)
Apr	0.292 (0.189)	0.163 (0.183)
May	0.355 (0.256)	0.158 (0.171)

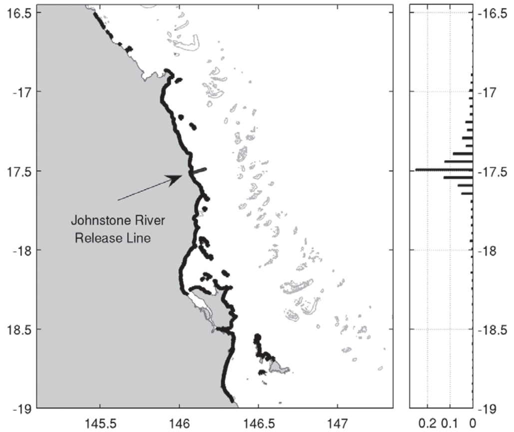

Figure 4. Johnstone River. Beaching map for releases in February 1998 to 2002. Histogram represents the latitudinal variation in beached particles.

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