Observations on the ecology and conservation status of *Haloragis exalata* subsp. *exalata* (Haloragaceae) in southern New South Wales

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***Abstract**: Haloragis exalata* F. Muell. subspecies *exalata* (family Haloragaceae), a perennial forb, is currently listed as Vulnerable, under both national and New South Wales threatened species conservation legislation. Very few herbarium records existed until recently.

Recent discoveries of *Haloragis exalata* subsp. *exalata* in new sites on the NSW South Coast and Southern Tablelands prompted us to carry out surveys for the two varieties of the taxon, var. *exalata* and var. *laevis*. Our surveys in 2004–2007 aimed to relocate historical collection sites and target areas of potentially suitable habitat in these areas.

Our work has substantially increased the number of known localities for *Haloragis exalata* subsp. *exalata* var. *exalata*. It can be locally abundant. Ecologically it appears to function as a gap species whose populations are almost invariably found at sites where disturbance through temporary inundation, physical disturbance, or fire, has exposed bare earth with higher levels of light at ground level than would be present when the local vegetation community is intact. There are morphological differences between populations in disjunct areas. *Haloragis exalata* subsp. *exalata* var. *laevis* is much more restricted.

As a result, the conservation status of *Haloragis exalata* subsp. *exalata* may need revision, considering that a) var. *exalata* is more widespread than previously known, but that b) there is only one known extant population of var. *laevis*, and that c) the population from Geehi area may be a distinct taxon.

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Introduction

Haloragis exalata (family Haloragaceae) is described as a shrub to 1.5 m high (Wilson 2002, Jeanes 1996) with 4-angled, red stems and opposite and decussate, toothed, lanceolate leaves. Inconspicuous flowers to 3 mm long are borne in extended leafy terminal or upper axillary inflorescences. *Haloragis exalata* is divided into two subspecies, *exalata* and *velutina* (subspecies *velutina* is restricted to northern NSW and Queensland, and not discussed further here). *Haloragis exalata* subsp. *exalata* is itself subdivided into two varieties, var. *exalata* (with scabrous stems and leaves) and var. *laevis* (distinguished by its glabrous stems and leaves).

Haloragis exalata subsp. *exalata* var. *exalata* has been historically recorded from a single location in the Hunter Valley (Moonan Brook near Scone in 1886) (Orchard 1990), the Nepean River near Sydney, Clifton near Wollongong and the South Coast (Tilba Tilba in 1880 and Mt Dromedary in 1889). Its habitat has been described as "damp riparian habitat" (Jeanes 1996) and "damp places near watercourses" (Wilson 2002). The majority of early herbarium specimens come from two areas in south-western Victoria: the Curdies River near Port Campbell (1894, 1900, 1966), and the lower Glenelg River (1891, 1945, 1946, 1950, 1954, 1969 and 1981). *Haloragis exalata* subsp. *exalata* var. *laevis* is apparently restricted to the Central Coast botanical division of NSW with historical records from the Nepean River and Parramatta (Orchard 1990).

Because of the very small number of modern records (prior to 2001), *Haloragis exalata* subsp. *exalata* is listed as Vulnerable under the NSW *Threatened Species Conservation Act (1995)* and nationally under the *Environment Protection and Biodiversity Conservation Act (1999)*. It is not listed under the Victorian *Flora and Fauna Guarantee Act (1988)*, although it is listed as vulnerable in Victoria on the *Advisory List of Rare or Threatened Plants in Victoria – 2005* (Department of Sustainability & Environment 2005).

In 2001–02 one of us (JM) discovered new populations of *Haloragis exalata* subsp. *exalata* var. *exalata* on the South Coast and in the Geehi Dam area of Kosciuszko National Park. Because of the conservation significance of *Haloragis exalata* subsp. *exalata*, we then followed up recent field records in the NSW South Coast, Illawarra and Kosciuszko regions with targeted field surveys to assess its current distribution, ecology and conservation status.

Methods

Specimens of the various subspecies and varieties of *Haloragis exalata,* and the related and very similar *Haloragis serra,* held at major herbaria (NSW, MEL, CANB) were examined. *Haloragis exalata* subsp. *velutina* is readily distinguishable from the remaining three taxa by the dense covering of short, uniform hairs on both stems and leaves. The other three taxa (*Haloragis serra* and *Haloragis exalata* subsp. *exalata* var. *exalata,* and var. *laevis*) are less easy to separate in the absence of fertile material (*H. serra* has 2-locular fruits and *H. exalata* 4-locular fruits) (Figures. 2, 3, 5).

Between 2004 and 2007 we carried out a series of targeted surveys on the NSW South Coast, revisiting the sites of past records to survey the areas more thoroughly, and searching numerous additional coastal lakes and estuaries which we considered might also harbour populations. Our surveys generally concentrated on the type of areas we had already found to be most likely to carry *Haloragis exalata* populations, low-lying shorelines and the mouths of small gullies. A large proportion of the shoreline of many of these southern lakes is steep, rocky and clothed with dry *Eucalyptus* forest and unlikely to be suitable for *Haloragis exalata*. Where the number of plants present was small (<50) an attempt was made to count individual plants, otherwise numbers were estimated, by counting a small area and extrapolating to the larger area. However, numbers are very difficult to estimate accurately due to the tangle of stems which forms when more than a few plants are growing together.

During the surveys we made observations on plant size and abundance, habitat and recruitment strategies and the impact of fire and disturbance regimes. Not all new populations were recorded as a result of targeted surveys: some additional serendipitous discoveries were made during other survey work. The surveys have been conducted over several years; some sites have been visited several times to observe responses to disturbance, principally flood events. For example a flood event affecting the Wallaga and Cuttagee Lake catchments in July 2005 opened both lakes to the sea, after a period of about 48 hours of very high water level. This provided an opportunity to observe the effect of a brief inundation on *Haloragis exalata* subsp. *exalata*, many plants of which were totally or partially submerged during this period. We carried out limited experimentation on seed germination and buoyancy in relation to flood conditions using samples of 100 freshly collected fruits.

We also looked at morphological variation in plants currently subscribed under *Haloragis exalata* subsp. *exalata* var. *exalata*, particularly between specimens collected from the south coast populations and those near Geehi in Kosciuszko National Park in the Southern Tablelands.

Haloragis serra (which is not listed as threatened) has been confused with *Haloragis exalata* subsp. *exalata* in both herbarium specimens and DECC Wildlife Atlas records. We therefore examined herbarium specimens and searched for it in Bungonia Gorge where it had previously been recorded, to clarify differences in appearance and habitat.

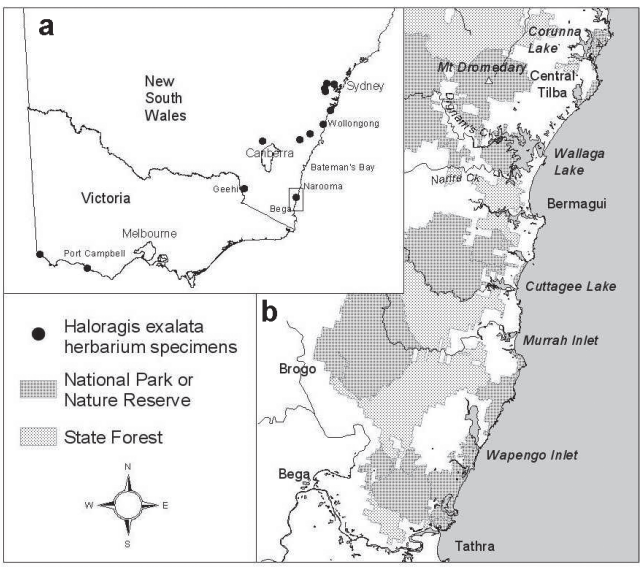

Fig. 1. a) Recorded collection sites of *Haloragis exalata* subsp. *exalata* and b) recently surveyed sites on the NSW far south coast.

Table 1 Current north to south geographical distribution of *Haloragis exalata* subsp. *exalata* var. *exalata* in southern New South Wales with field observations on population numbers (2004–2007), and locations of some related *Haloragis* taxa that have caused confusion.

a) Current distribution of *Haloragis exalata* subsp. *exalata* var. *exalata*

Otford to Coledale

In February 2007 we found only 6 plants, on a small, weedy area of road verge adjacent to a regrowth rainforest patch at Coalcliff, after searching between Otford and Coledale, concentrating on riparian sites and areas of waste ground, within this now predominantly suburban setting. There is an 1889 specimen from Clifton, within this area, and Fairley (2004) reported that *Haloragis exalata* subsp. *exalata* var. *exalata* was *rediscovered in 1992 and is now known from three locations in the Illawarra (Stanwell Park, Coalcliff, Coledale) and from Berry where it grows on margins of rainforest and along damp creek banks,* but it was not possible to obtain further information about these records, which are apparently not supported by herbarium specimens or DECC Wildlife Atlas records.

Shoalhaven River

A specimen collected by K. McDougall from the Shoalhaven River/ Bungonia Creek confluence appears to be *Haloragis exalata* subsp. *exalata* var. *exalata*, but plants of this taxon could not be relocated in this location in 2006.

Shoalhaven Gorge and Bungonia Creek -see under c)*Haloragis serra*.

Durras Lake, north of Batemans Bay

40 plants, mostly seedlings recorded in 2006 on road verge adjacent to an arm of Durras Lake.

Tuross Lake, south of Moruya

3 plants recorded in 2006, in a canopy gap created by a fallen *Casuarina glauca*.

Wagonga Inlet, west of Narooma

A large *Haloragis exalata* population (>500 plants) found in pasture on the edge of forest on a small freshwater drainage line flowing into Wagonga Inlet in 2006.

Nangudga Lake, south of Narooma

24 plants were found on a small creek flowing into Nangudga Lake in 2006, on creek edges and forest/pasture edges.

Corunna Lake, 8km north of Wallaga Lake

An estimated 300 plants, scattered in 9 locations around the northern shoreline (the only area searched) in 2004–5.

Mt Dromedary

Existing tracks on Mt Dromedary searched in 2005 but no plants, nor any likely riparian habitat seen. However, when historical collections were made (1880, 1889), the mountain was extensively disturbed by goldmining, and numerous additional tracks and clearings, now over-grown, would have been present, and may have provided habitat. Alternatively, the reference to Mt Dromedary on the 1889 specimen may refer to the district rather than the mountain itself. The "Tilba Swamp" of one historical record probably refers to Bobundara Swamp, which is now on farmed private property, and has not been searched.

Wallaga Lake

Haloragis exalata subsp. *exalata* var. *exalata* was recorded in 2001 during a weed survey of Snake Island in Gulaga National Park, in the delta of Dignams Creek, where it enters Wallaga Lake. In 2004–05 we undertook surveys of parts of Snake Island and the Wallaga Lake foreshore where we found several sub-populations varying from one to several hundred plants scattered around most of the shoreline.

Dignams and Narira Creeks

Dignams Creek rises south and west of Mt Dromedary. We undertook a survey of the non-tidal section of Dignams Creek, walking along 6 km of creek frontage. Dignams Creek above the tidal limit carried several hundred plants scattered along 3 km of creek frontage, though an additional 3 km searched immediately upstream had no plants. Narira Creek, the other major tributary of Wallaga Lake, was searched up to the limit of navigability by boat. By contrast with Dignams Creek, most of the Narira Creek catchment and banks have been cleared for dairy farming, so surveys of the non-tidal section were considered unlikely to be productive.

Cuttagee Lake, 12 km south of Wallaga Lake

Four sub-populations of 3, 30, 50 and c. 100 plants were located in 2004–05, and have been monitored through several changes in lake levels since then, varying in total population size between 27 and 200 plants.

Geehi Dam, 3–4 km west of the Kosciuszko Main Range (1100m elevation)

In 2002 *Haloragis exalata* subsp. *exalata* var. *exalata* was discovered scattered on road verges and a powerline easement (ngh environmental 2003a). Initial surveys were confined to the verges of roads and other disturbed sites around the dam.

In December 2003 the response of *Haloragis exalata* to the January 2003 Kosciuszko wildfires was observed (ngh environmental 2003b). Ten months after the fires thousands of seedlings were found extending up slopes above roads near the dam in burnt forest, but on an unburnt powerline easement there was no apparent change in plant numbers. The bed of the Geehi River was surveyed over a limited area immediately below the dam wall, where it has been substantially modified by loss of flow and weed invasion but no *Haloragis exalata* was found.

A third survey in June 2005 extended the occurrences of *Haloragis exalata* up to 14 km from the dam wall along Olsens Road, and established that the plants extend for more than 50 m above roads and tracks in burnt forest. The populations originally detected on road verges and probably unaffected by the fires were still present.

b) Current distribution of *Haloragis exalata* subsp. *exalata* var. *laevis*

Gooseberry Island, Lake Illawarra

In July 2005, after a reasonably thorough search of the entire island shoreline and some of the interior, we recorded only 20 plants, in 3 clumps, spread over 150m of shoreline in canopy gaps between the *Casuarina glauca* fringe and the interior rainforest. This is the only extant population known of this taxon. Weed infestations could represent a substantial threat.

c) Some current locations for *Haloragis serra*

Shoalhaven Gorge

A specimen originally identified as *Haloragis exalata* subsp. *exalata* var. *exalata* was collected from the walls of the Shoalhaven Gorge in 1985 (CANB specimen). Habitat notes state "Steep rocky slope, gully edge, NE aspect. Skeletal soil on meta-sediments. Open forest, *Eucalyptus tereticornis, Olearia viscidula, Myoporum montanum*". The collection is from 400m elevation, substantially above the level of the Shoalhaven River at this point (140m), and so not riparian. The specimen was subsequently re-determined as var. *laevis*, but on appearance and habitat it appears to us more likely to be *Haloragis serra*.

Tallowa Dam

A similar specimen (held at NSW Herbarium), was collected in 1988 below Tallowa Dam. We relocated this population - 15 plants growing among rock scrub in skeletal soils on sandstone, well above the riparian zone. Dr Peter Wilson confirmed that our collection from this site, and the 1988 specimen, are both *Haloragis serra*.

Bungonia Creek

In 2004 *Haloragis exalata* subsp. *exalata* var. *exalata* was recorded by one of us (JM) in the bed of Bungonia Creek (ngh environmental 2005). A re-survey of this area in January 2006 found that the scattered large fruiting plants present in the creek bed were, in fact, *Haloragis serra*, despite the riparian habitat being more typical of *Haloragis exalata*. *Haloragis serra* of more typical compact habit also occurs on limestone pavement at the top of the gorge.

Fig. 2. *Haloragis exalata* subsp. *exalata* var. *exalata* at Dignams Creek, near Bermagui. Stems and leaves are scabrous. Reduced leaves in the flowering region have sparser teeth, similar to those of *Haloragis serra*.

Fig. 3. *Haloragis exalata* subsp. *exalata* var. *laevis* at Gooseberry Island, Lake Illawarra. Stems and leaves are completely glabrous.

Fig. 4. *Haloragis exalata* fruiting plant at Geehi, showing the relatively broad leaves found in this population.

Fig. 5. *Haloragis serra* near Tallowa Dam, showing the relatively sparser and longer teeth on leaf margins.

Results

Distribution of Haloragis exalata subsp. exalata

The results of our surveys (Table 1a) show that *Haloragis exalata* subsp. *exalata* var. *exalata* currently occurs along the NSW coast from Coalcliff to Cuttagee Lake south of Bermagui, and in the Southern Tablelands at Geehi in Kosciuszko National Park. Coastal water bodies on the South Coast on which we could find no occurrences of *Haloragis exalata* were the Bermagui River estuary, Murrah Lagoon, Middle Lagoon, Wapengo, Barragoot, Nargal and Mummaga Lakes. Quite a number of south coast lakes remain unsurveyed, and in most of those which have been surveyed only part of the shoreline has been covered, so there is potential for additional populations to occur. Populations historically recorded in western Sydney and the Hunter Valley are not known to exist currently, though cannot be said to be locally extinct until targeted searches have failed to find them. We did not conduct searches in these areas. Nor did we survey the areas in Victoria where it has formerly been recorded.

In contrast, the distribution of *Haloragis exalata* subsp. *exalata* var. *laevis* is much more restricted (Table 1b). If specimens from the Shoalhaven River are *Haloragis serra*, as appears to be the case, the only known extant occurrence of this taxon is the single small population on Gooseberry Island in Lake Illawarra.

Within the current distribution of *Haloragis exalata* subsp. *exalata,* environmental disturbance by Europeans is likely to have been most intense, and to have operated over the longest period, in the Sydney and Illawarra areas. The Coalcliff and Gooseberry Island populations appear to be the least thriving of all those examined.

Variation between Geehi and South Coast populations of Haloragis exalata subsp. *exalata* var. *exalata*

We found morphological differences between Geehi and South Coast specimens identified as *Haloragis exalata* subsp. *exalata* var. *exalata*. These morphological differences include the shape and colour of stems, and differences in leaf shape, leaf indumentum and leaf arrangement (Table 2) (Figure 4). The population at Geehi is not tied to riparian habitat, but extends widely over at least the lower slopes within tall wet sclerophyll forest, a habitat quite dissimilar to that in which it occurs on the NSW South Coast. These differences and their disjunct distributions (separated by at least 170 km and 1100 m elevation), suggest that the Geehi population should be investigated as a possible discrete taxon.

Haloragis serra

Notes accompanying *Haloragis serra* specimens suggest that it occurs frequently, but not exclusively, in rocky sites, with an affinity for limestone (with specimens from Wee Jasper, Jenolan Caves, Abercrombie Caves and Bungonia Caves). There are also specimens from sandstone in Marramarra National Park on the Hawkesbury River (possibly influenced by calcareous midden material – Doug Benson pers. comm.) and at Tallowa Dam, Shoalhaven River (Table 1c), and other geologies (Warrumbungle Range, *skeletal clay loam on trachyte*). The majority of specimens come from the NSW Tablelands and Western Slopes.

In the absence of fruiting material the best distinguishing feature between *Haloragis serra* and *Haloragis exalata* appears to be the teeth of the leaf margin, which are widely spaced and excurved with an acuminate tip in *Haloragis serra* and more numerous, crowded and blunter in *Haloragis exalata* subsp. *exalata*, though reduced leaves in the flowering region approach those of *Haloragis serra* in appearance.

Growth form of Haloragis exalata subsp. exalata

Our observations suggest that *Haloragis exalata* subsp. *exalata* var. *exalata* is more a perennial forb than a shrub, despite its large size. It may reach over 2 m in height, though 1–1.5 m is more common. It does not form a permanent woody stem, but produces masses of stems from the base. Stems are relatively lax and layering has occasionally been observed in prostrate stems. Our observations of var. *laevis* are limited, but its morphology is similar.

Flowering and fruiting

In common with many Australian plants, timing of reproductive activity may be tied more closely to rainfall than to temperature or day length. Plants flowered and fruited through January–February in 2005 at Wallaga and Cuttagee lakes, but the following summer many plants had largely finished flowering by the end of December. It seems likely that the Geehi plants (at 1100m elevation) flower somewhat later in the season as a few still bore fruits in June 2005. Plants in full sunlight appear to be more likely to flower and set fruit than those in more shaded sites, and flower earlier. The inconspicuous flowers are believed to be wind-pollinated (A. Orchard, pers. comm.).

The fruits, each potentially containing up to four seeds, are shed very freely when the plant is brushed or shaken. In the coastal populations, following seed drop the terminal inflorescence withers and the plant produces new lateral branches lower on the stem. New stems also arise from the base of the plant, with vigorous growth continuing through the winter. In the Geehi plants new growth from laterals appears to be rare and in most cases the stems die back completely after fruiting to be replaced by new stems.

Table 2 Morphological differences between NSW South Coast and Geehi specimens of *Haloragis exalata* subsp. *exalata* var. *exalata*

Character	Typical coastal plants	Geehi plants
Stems	Conspicuously red stems, 4-ridged	Stems more often green, less square in profile
Leaf shape	Narrower, longer leaf: length:width ratio averaged 4.66:1 (range 10.5–12 x 2.4–2.5cm) on a typical plant from Corunna Lake.	Shorter, broader leaf: length:width ratio averaged 1.97:1 (range 8.5–9 x 4.5–5cm) on a single representative plant.
Leaf indumentum	Short stiff hairs, rough surface texture.	Indumentum shorter and denser, giving a velvety texture.
Leaf arrangement	Leaves mostly opposite, reducing in size and becoming alternate only in the flowering region.	Leaves may be alternate from the base on new shoots, shoots with opposite and shoots with alternate leaves may occur on the same plant, as well as reduced, alternate leaves in flowering region.

Seed germination

The fruits are indehiscent, so seed presumably does not germinate until the surrounding fruit has broken down sufficiently to allow water penetration. As the outer covering is quite hard, this may take some time. At Cuttagee Lake where plants fruited profusely in the summer of 2004–05, no seedlings were observed to have germinated by the following spring. By summer however, more than 30 seedlings were present.

In one of our small experiments, two samples of 100 freshly collected fruits were sown, one watered daily, and the other kept permanently flooded to simulate lake margins conditions. Germination took about three weeks and was poor in both, with a total of only 5 seedlings emerging from 200 fruits. The seed punnets were maintained for a further six months, with no additional germination occurring. In a dissected sample of 20, half the fruits were found to contain no seed, which may partially explain the poor germination rates.

Seed dispersal

Seed appears to be transported by water and fruits have been found to be quite buoyant. In a buoyancy experiment, 100 ripe fruits were agitated in water and left to settle – 72 were still floating after 30 hours. A feature of many coastal colonies is the arrangement of plants in distinct lines which appear to represent water levels during high stand events in the lakes or floods in the creek. It seems probable that this patterning is produced by the deposition of waterborne seeds.

Other species of *Haloragis* have been observed to be myrmecochorous (A. Orchard, pers. comm.) and it is possible that ants also collect and store the fruits of *Haloragis exalata* subsp. *exalata*. However, if it occurs it is likely to be a minor factor in coastal populations, as ant dispersal only occurs over small distances.

Herbivory

Some browsing was observed at a small number of sites but *Haloragis exalata* subsp. *exalata* does not generally seem to suffer serious damage by vertebrate herbivory, though occasional browsing by swamp wallabies (*Wallabia bicolor*) of some individual plants within a population may occur. The two small Narira Creek colonies were heavily browsed on each of the three occasions they were seen, but appeared to be persisting despite this, at least over the period 2001–2005.

Damage by insects appears to be rare, though a few plants on Dignams Creek carried large numbers of a small iridescent blue beetle (*Altica* sp. Galerucinae: Chrysomelidae) and up to 50% of the area of many of the leaves had been consumed.

Plant longevity

The longevity of the plants is currently unknown. It seems likely that an individual plant would continue to produce new stems until killed outright by an event such as fire or prolonged inundation, or possibly in some locations until shaded out by increasing canopy density. Plants on the upper banks of Dignams Creek seem likely to have germinated after the last major flood in December 1992, since there have been no floods since that time which would have reached the upper bank level. These plants would be 14 years old at the time of writing (2007).

Habitat preferences and recruitment

Populations of *Haloragis exalata* subsp. *exalata* are largely associated with some form of disturbance which temporarily bares the ground and often results in a degree of canopy breakdown and an increase in light intensity at ground level. The disturbance mechanisms on coastal sites include erosion and deposition by floodwaters, prolonged inundation during periods of lake closure, gap creation through weed control activities and canopy tree collapse.

On coastal sites *Haloragis exalata* subsp. *exalata* tends to occupy the most moist and naturally fire protected areas in the landscape, and it is improbable that fire is a significant disturbance factor here. The population on Dignams Creek is almost entirely confined to the zone subject to occasional flood disturbance. Numerous plants have colonised stream bed and anabranch alluvial deposits. Other individual plants and colonies are on higher banks but still within the zone affected by major floods. A few plants on the edges of a track which fords the creek are above flood level.

The populations of Corunna, Wallaga and Cuttagee Lakes are largely associated with sites affected by prolonged lake-shore inundation, with the occasional colony in areas of human disturbance such as roadside drains. All three lakes are classed as Intermittently Closed and Open Coastal Lakes and Lagoons (ICOLL) and alternate between tidal phases and phases when they are closed to the ocean by sandbars. As a result of rain during the closed phase the lakes may stand for periods of several months at considerably higher levels than are attained at the highest tides. The resulting inundation by saline water commonly results in the death of shore plants unable to tolerate these conditions (Figure 6).

Corunna, Wallaga and Cuttagee Lakes have each undergone lengthy periods of high water levels interspersed with lower lake levels during the four dry years, 2002–2006. The size of some drowned trees suggests that similar inundation events have not occurred for about 20 years. *Haloragis exalata* subsp. *exalata* has been observed predominantly in those zones where inundation has killed vegetation, creating canopy gaps and bare ground and, in many cases, where it

has resulted in the deposition of a line of debris. It frequently occurs with a number of native and exotic asteraceous species (*Senecio linearifolius, Senecio minimus, *Aster subulatus, *Cirsium vulgare, *Conyza albida*), which also exploit these gaps in the lake shore vegetation (*denotes exotic species).

Waterways that are permanently open to the sea generally lack such canopy gaps and searches of the Bermagui and Murrah River estuaries and Wapengo Lake, all permanently open, located no *Haloragis exalata*. A large population was found on one permanently open waterway, Wagonga Inlet, although in this case the population was not on the lake margin, but associated with a small freshwater gully passing from forest into a cleared paddock, just above tidal level.

A small number of plants found on the normally tidal Tuross Lake were associated with a canopy gap created by a fallen *Casuarina glauca* tree, adjacent to a rainforest stand and well above the potential high stand level. On Gooseberry Island *Haloragis exalata* subsp. *exalata* var. *laevis* plants are associated with patches where **Lantana camara* has died or been removed, within the fringing *Casuarina glauca* forest and apparently above normal high water level.

The availability of moisture may limit the extent of coastal colonies. Prior to drought-breaking rains in July 2005, plants on the drier upslope margins of the lake shore colonies were observed to be suffering water stress, wilting before any other species in the vicinity. Only at Geehi are plants widely dispersed, in a habitat which is uniformly relatively moist.

At Geehi disturbance mechanisms include fire, baring of soil by human and animal excavations and creation of canopy gaps on powerline easements and along roads.

Response to flooding

A flood event affecting the Wallaga and Cuttagee Lake catchments in July 2005 opened both lakes to the sea after a period of about 48 hours of very high water level. Many plants of *Haloragis exalata* subsp. *exalata* were totally or partially submerged during this period. At a Cuttagee Lake site adjacent to a tributary creek where the water around the plants was fresh, the plants appeared to be unaffected by their immersion, but a site near the mouth of Wallaga Lake, remote from floodwater inflows and where the inundation would have been by saline water, the plants were severely burned.

Ten weeks after the flood event all above-ground portions of these Wallaga Lake plants were dead; six months later these plants showed no signs of resprouting, nor was any seedling germination evident. Plants above the high water mark appeared to have been burned to some extent by wind-blown salt, but were gradually recovering, and in some cases flowering sparsely. It appears that the plants are not highly salt tolerant; this may partially explain their distribution around the lake margins, which is frequently in areas of freshwater inflow.

Following the same flood event, plants in the stream-bed of Dignams Creek were found to have been wholly submerged, partially flattened and severely battered, to the extent that leaves were being shed. No plants had been wholly dislodged and a week after the flood peak the growing tips of flattened stems had reoriented upwards. Six months later these stream-bed plants had fully recovered, with new lateral shoots growing up from the flattened stems, even in plants whose root systems had been partially uncovered (Figure 7).

Fig. 6. *Haloragis exalata* habitat on Cuttagee Lake, south of Bermagui. Plants are located within the dead vegetation behind the strandline belt of *Suaeda australis*.

Fig. 7. *Haloragis exalata* subsp. *exalata* var. *exalata* at Dignams Creek after flooding, with the base of the plant well anchored in the loose substrate.

In July 2006 rain resulted in a high stand event which inundated all populations at Cuttagee Lake for 25 days (until the lake was artificially opened). All but the most upslope plants progressively died - by February 2007 only 7 mature plants and 20 seedlings remained on the lake shore. The population had peaked in early 2006 at more than 200 plants.

Response to fire

At Geehi, various disturbance factors are operative, but the most important agent is fire, the January 2003 Kosciuszko wildfire having established conditions for the germination of a very large population extending discontinuously over at least 14 km. Given the dissection of the terrain, the effects of any one fire are likely to be spatially variable and within this patchy distribution *Haloragis exalata* subsp. *exalata* can be present in thousands. The density was found to vary considerably. In some locations *Haloragis exalata* is a dominant species in the regenerating understorey, particularly on a burnt powerline easement, where a tree canopy was lacking. It occurred both in areas which had burnt at high intensity (indicated by death of the canopy Alpine Ash, *Eucalyptus delegatensis*), and areas where the understorey had been burnt, but with no canopy scorch. On the basis of limited observations in two areas, it appeared to be more abundant in a lightly burnt area which had a more grassy understorey, compared with a high fire intensity site, where there was very dense regeneration of tree and shrub seedlings (mostly *Eucalyptus delegatensis* and *Daviesia latifolia*). However it is not clear whether this difference relates directly to the fire intensity, to pre-fire differences in the understorey, or to differing density of the post-fire regeneration.

The size of the response to this fire implies considerable longevity for seeds in the soil seedbank. While fires of the intensity and extent of January 2003 are uncommon, fires occurred in the Geehi Dam vicinity in summer 1972–3, and in 1993, 30 years and 10 years previously (Craig Smith, Ranger, Geehi/Jagungal, pers. comm.).

The formation of roads and tracks results in canopy disruption and exposure of bare earth. *Haloragis exalata* occurs on road verges at Geehi Dam, Dignams Creek, Wallaga Lake, Corunna Lake and Coalcliff and small numbers of seedlings have been observed in soil disturbed by animal excavations at Geehi and Corunna Lake. Our observations suggest that in the absence of fire a small number of plants would persist at Geehi in such disturbed sites as track verges, landslips and where soil is disturbed by wombat excavations.

Discussion

Rarity

The distribution pattern and apparent habitat preferences of *Haloragis exalata* subsp. *exalata* pose interesting questions. Recorded populations are widely disjunct, with 500 km separating the Victorian and Geehi populations and 170 km between Geehi and the nearest NSW coastal population. There are substantial differences in habitat between the coastal and Geehi populations.

Despite its overall 'rarity' within its extent of occurrence, *Haloragis exalata* subsp. *exalata* can be locally abundant. It fruits profusely (though seed production may be lower than appearances suggest as some fruits are empty), its seeds must have considerable longevity and it is capable of regenerating in dense stands when conditions are suitable. Once established it competes fairly successfully with exotic weeds and it does not appear to be subject to much herbivory by either vertebrates or invertebrates. It is evidently advantaged, at least in the long term, by disturbance. Indeed the apparent rarity may be to some degree an artefact of observation, as it is obvious and likely to be observed in the landscape only after appropriate disturbance events and may otherwise be present only or mainly in the soil seed bank. Given these characteristics it is surprising that *Haloragis exalata* subsp. *exalata* is not more widespread across south-eastern Australia. In New Zealand the closely related *Haloragis erecta* is widespread and abundant, and according to Forde (1964) *almost becoming a weed in some local areas*.

Forde's (1964) thesis that the closely related *Haloragis* species of Australia, New Zealand and the Juan Fernandez Islands (off Chile) represent disjunct components of a single species complex in evolution is worth consideration. It is possible that the restricted geographic range of *Haloragis exalata* subsp. *exalata* may be 'incipient' rather than 'relictual', (to use the terminology of Rabinowitz 1981); that its rarity is that of a plant still at a relatively early stage of colonisation and speciation in south-eastern Australia. The coastal habitats of the species are of recent geomorphology, formed since the post-glaciation inundation of coastal valleys within the past 20,000 years, and its high altitude Geehi habitat is hardly likely to have supported the current suite of species during glacial phases.

Threatening processes

The majority of NSW *Haloragis exalata* subsp. *exalata* populations occur within conservation areas. The Geehi plants are within Kosciuszko National Park and Gooseberry Island is in Berkeley Nature Reserve. The occurrence of the taxon (if present) on the Shoalhaven River is likely to be within Morton National Park or Bungonia State Conservation Area. Around the South Coast lake-shores colonies occur on a diversity of tenures, but the majority are on public land managed by the NSW Department of Environment and

Climate Change and the Bega Valley and Eurobodalla Shire Councils. Three riparian populations are on freehold tenure.

We consider that the two greatest threats are displacement by weeds, and cessation of the disturbance-inducing processes upon which the plant appears reliant. Some of the coastal sites where *Haloragis exalata* subsp. *exalata* occurs, particularly Gooseberry Island, Coalcliff, Snake Island and the banks of Dignams Creek, are moderately to heavily infested with environmental weeds, particularly **Lantana camara, *Asparagus asparagoides, *Delairea odorata, *Araujia sericifera* and **Rubus ulmifolius*. The existing *Haloragis exalata* populations at these sites presumably established in the presence of these weeds, though perhaps after they, like the canopy of native shrubs and trees, had been damaged by flooding, clearing or weed control activities. *Haloragis exalata* appears to be a strong competitor with weed species. Nevertheless at some sites weed invasion is at a relatively early stage and, without effective intervention, *Haloragis exalata* may eventually be seriously disadvantaged. That few plants could be found in the Illawarra populations suggests that it is faring less well in these relatively weedy areas, compared with the less degraded coastal habitats of the far South Coast. The only population of var. *laevis* is probably already suffering adversely from competition from dense **Lantana camara* infestations on Gooseberry Island. An additional potential threat is of destruction of plants during weed control operations.

Maintenance of recruitment regimes

As discussed above, different disturbing processes operate at different sites. There is no reason to suppose that the fire regime to which the Geehi population is subject will change, so as to diminish the requisite disturbance. Likewise floods will continue to advantage riparian and lake shore populations of *Haloragis exalata*, although both flood and fire frequencies could be affected by anthropogenic climate change.

Inundation-induced disturbance of lake shore vegetation can only occur if the responsible authorities leave the lakes to stand at high levels for lengthy periods. Such high stands are contentious since they damage or render temporarily unusable such assets as jetties, roads, caravan park sites and pastures. At the time of writing there was a proposal to construct breakwaters at the entrance of Lake Illawarra with the intention of reducing sand in-flow and thereby reducing or eliminating periods when the lake is closed. If these works are constructed and function as intended, the Gooseberry Island population may be disadvantaged, and some active manipulation of its habitat may be required to offset this.

The populations along the lakes and estuaries of the far South Coast appear to have persisted through more than a century of partial catchment modification, and may currently be at unusually high levels due to high stand events over the past four years of drought. Its wide distribution around several lakes and estuaries offers a degree of insurance against events or processes which might destroy individual colonies and suggests that recolonisation of suitable sites would be likely to occur eventually, without the need for human intervention. However, if riparian colonies are dependent upon replenishment by seed carried from upstream sites, it may be important to ensure that the most upstream colonies are conserved and protected.

Conservation assessment

To be eligible for listing under IUCN Red Book guidelines *Haloragis exalata* subsp. *exalata* needs to satisfy one of the following five criteria:

- Criterion A (population reduction): In NSW recent survey effort has dramatically increased the number of known populations, with plant numbers being very large in some of these. *Haloragis exalata* subsp. *exalata* does not satisfy this criterion.
- Criterion B (geographic range): Recent discoveries of the taxon have also increased the geographic range, which has been extended out to the Snowy Mountains, although truncated at the northern end of the range through probable loss of populations in the Sydney area. There are also no recent records from the Hunter Valley. The range would exceed 20 000 km^2, the upper limit for consideration as vulnerable. Within its range the taxon is naturally fragmented in distribution. It would be eligible for listing as vulnerable if the area of occupancy within its range could be shown to be <2000km^2, the number of locations at which is it known is 6–10 and it undergoes extreme fluctuations in numbers of mature individuals. The first two points may be true, although in the absence of a thorough survey of the Snowy Mountains there is no knowing how large an area it may occupy there. It is quite likely that it occurs in other areas besides the Geehi Valley. The number of locations depends on the definition of location, but if each lake from which there is a formal record (voucher specimen or DECC Wildlife Atlas record) is taken to be a single location, and the Geehi population as another, then the current number of known locations is ten for this taxon, with another three reported locations between Berry and Stanwell Park for which no data is available. Although it appears to undergo large population fluctuations, the guidelines for interpretation of the IUCN criteria specifically exclude organisms with a "boom and bust" life cycle such as *Haloragis exalata* subsp. *exalata* from being considered under this criterion. It therefore does not satisfy sufficient points under criterion B.
- Criterion C (small population size and decline) and D (very small or restricted population): *Haloragis exalata* subsp. *exalata* var. *exalata* does not satisfy these criteria.
- Criterion E (quantitative analysis): insufficient data are available to apply this criterion.

A reassessment of the level of threat facing *Haloragis exalata* subsp. *exalata* based on the IUCN criteria using our recent data suggests that *Haloragis exalata* subsp. *exalata* var. *exalata* may not now satisfy criterion for listing as Threatened, at least in NSW. Further survey effort in Victoria would be required to determine the current status of populations there.

The same is not true of *Haloragis exalata* subsp. *exalata* var. *laevis* however, which is restricted to a local population of 20 plants on Gooseberry Island in Lake Illawarra, and would appear to be eligible for listing as critically endangered (with a known population of <50 mature individuals).

A National Recovery Plan for *Haloragis exalata* subsp. *exalata* (Carter, in prep.) recommends ensuring the continuance of natural or anthropogenic disturbance regimes applicable at each site, undertaking weed control, ongoing monitoring of all populations, further survey and research into the reproductive biology of the taxon. These recommendations are particularly urgent with respect to *Haloragis exalata* subsp. *exalata* var. *laevis*, though the Recovery Plan does not make this point.

There is much still to be learned of the life history and ecological role of *Haloragis exalata* subsp. *exalata*. Closer study may yield useful insights applicable to a whole class of plants sharing its status of apparent rarity and dependence upon stochastic disturbance-inducing events, many of which are also listed as threatened in NSW.

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