Evaluation of the state of *Didymosphenia geminata* in the Waiau Arm following a four-month 'park and flush' regime

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Executive Summary

- Live cells of the invasive alga *Didymosphenia geminata* were first confirmed in the Waiau Arm in April 2005 (Kilroy and Blair 2005). In August 2005 an extensive benthic survey of the Arm indicated that the deposition/dispersal of *D. geminata* extended half way into Zone 2, a further 2.4km upstream than previously thought. *D. geminata* was confirmed to be growing periphytically and epiphytically in the Waiau Arm.

- In an effort to prevent further translocation of cells up the Waiau Arm and into Lake Manapouri, Meridian Energy adopted a conservative operational flow regime in the Waiau Arm following scientific advice from NIWA. The new 'park and flush' regime, adopted in August 2005 now means that the environment in the Waiau Arm is analogous to that of a lentic habitat. Little is know about *D. geminata's* ability to thrive in this type of environment, however, it is thought to colonise stable substrates within the wave wash zone of lakes.

- In order to assess the effect the 'park and flush' regime on *D. geminata* a benthic survey across and along parts of the Waiau Arm and in 'hot spots' areas of Lake Manapouri. The objective of this survey was to determine if *D. geminata* was able to survive in a lentic-like environment currently present in the Waiau Arm and thus present a secondary source of material that could be transported to Lake Manapouri.

- Macroscopic growths of viable *D. geminata* were found growing attached to logs near the river mouth entrance into Shallow Bay. Drift mats of *D. geminata* were observed travelling into the lake moving along water currents derived from the Upper Waiau River. No macroscopic growths of *D. geminata* were observed along Frasers Beach and east of Richters Rock. Two *D. geminata* cells, one containing intact chloroplasts, were found in a single benthic sample collected from silt sediment on the east side of Richters Rock.

- 99% of all *D. geminata* cells sampled from Zone 1 were found to be dead cells (defined as either empty frustules or with constricted chloroplasts). In the shallow, cobbled area near the MLC, stalked material persisted attached to rocks with large accumulation of organic matter and bacteria on the stalks.

- There does not appear to be a further upstream extension of *D. geminata* in the Waiau Arm since the August 2005 survey. Historically, upstream movement of *D. geminata* in the Waiau Arm was significantly assisted by diversion of Mararoa River water into the Arm and up towards the lake. Since the adoption of the 'park and flush' operational regime by Meridian the risk of flow-assisted movement to the lake as all but been eliminated. Transport by other vectors, such as wind, fish, birds and human activities still poses a threat to the lake.

- Parking of the water in the Waiau Arm was expected to lead to unfavourable for supporting the continuation of prolific growths of *D. geminata*. The results from the present survey indicate that this is indeed true, with approximately 99% of the *D. geminata* sampled consisting of dead frustules. This is in sharp contrast with the August survey results where over 75% of cells examined were found to be healthy and viable. The most likely explanation for the demise of *D. geminata* in the Waiau Arm is the reduction in supply of nutrients to the cells across the boundary layer.

- Since the 'parking' of water flow in the Waiau Arm native macrophytes have proliferated in the shallow reaches of the Arm while native characeans have formed lush meadows in the deeper parts, increasing the overall health of the Waiau Arm.

1. Introduction

Live cells of the invasive alga *Didymosphenia geminata* were first confirmed in the Waiau Arm in April 2005 (Kilroy and Blair 2005). At the time of this survey (and subsequent monthly surveys) benthic samples collected from 0~1m water depth suggested that *D. geminata* was confined to the lower downstream part of the Waiau Arm (termed Zone 1) and did not appear to be actively growing in the Arm itself. However, in August 2005 an extensive benthic survey of the Arm indicated that the deposition/dispersal of *D. geminata* extended half way into Zone 2, a further 2.4km upstream from the last know positive site. Furthermore, *D. geminata* was confirmed to be growing periphytically and epiphytically in the Waiau Arm (Sutherland et al. 2005).

In an effort to prevent further translocation of cells up the Waiau Arm and into Lake Manapouri, Meridian Energy adopted a conservative operational flow regime in the Waiau Arm following scientific advice from NIWA. This new regime, termed 'park and flush', has been in operation since August 2005. Under the 'parking' of the Arm no water is diverted from the Mararoa River into the Waiau Arm towards lakes, while a slight positive flow from the lake towards the MLC prevents any backflow from the river into the Arm. 'Flushing' of the Waiau Arm involves the complete replacement of water in the Arm from the lake and pushed out towards the MLC. Flushing the water out of the Arm will be necessary when quality of water is considered to have deteriorated. This regime has been in operation for four months and the environment in the Waiau Arm is now analogous to that of a lentic habitat. Little is know about *D. geminata's* ability to thrive in this type of environment, however, it is thought to colonise stable substrates within the wave wash zone of lakes (see Kilroy 2004).

In order to assess the effect the 'park and flush' regime is having on *D. geminata* in the Waiau Arm, NIWA was commissioned by Meridian Energy to undertake a benthic survey across and along parts of the Waiau Arm. Areas within Lake Manapouri that were also of concern were included in this survey. Historically, Frasers Beach and east of Richters Rock were two sites within Lake Manapouri most at threat to *D. geminata* invasion through means of water movement up the Arm and into the lake. Since the 'parking' of the Arm, this water movement is no longer regarded as a possible dispersion vector of *D. geminata* to these sites. However, transport by wind, bird, fish and human-mediated movement from the Arm or from other sites were still possible. Shallow Bay forms at the mouth of the Upper Waiau River. *D. geminata* was first confirmed growing in the Upper Waiau River in September 2005. Water flowing directly from the river into Shallow Bay poses the greatest risk of *D. geminata* transfer into Lake Manapouri.

The objective of this survey was to determine if *D. geminata* was able to survive in a lentic-like environment currently present in the Waiau Arm and thus present a secondary source of material that could be transported to Lake Manapouri.

2. Methods

2.1. Benthic surveys

Benthic surveys of Lake Manapouri and the Waiau Arm were conducted on 29-30 November and 1 December 2005. Three sites in Lake Manapouri considered most vulnerable to early infestation, Frasers Beach, east side of Richters Rock and Shallow Bay, were surveyed for the presence of *D. geminata*. Drift SCUBA dives were conducted along 200m of shoreline to visually assess for macroscopic growths of *D. geminata* across a 3m wide band. 20 benthic samples were collected along each lake profile from a water depth between 1-1.5m. Five transects were surveyed in Zones 2 and 3 of the Waiau Arm, upstream of the positive sites from the August survey. The boat ramp at Pearl Harbour was targeted as a transect site due to the high risk it presents from the introduction *D. geminata* from areas outside the Waiau Arm. At each transect divers, on SCUBA, collected 10 benthic samples spaced at even distances along the profile at right angles to the shoreline. At each sampling point benthic samples were collected from the range of substrata present (sediment, rock, log or macrophyte) and were pooled as one sample. Descriptions of the substrate type, macrophyte community, distance from shore and water depth were recorded. In addition, periphytic and epiphytic algal communities were described from a 2 m wide band along the transect profile.

Twenty additional sites were randomly selected within Zones 2 and 3 for the collection of a single sample at approximately 1-1.5 m water depth.

Within Zone 1 two transects previously sampled during the August survey were re-sampled for comparison. These transects were transect 29 and 31. Benthic samples were collected as described above. In addition, a single drift dive was conducted from transect 29 down to the shallow region towards the MLC. This area was visually inspected for the presence of macroscopic growth of *D. geminata* and 20 samples were collected from the benthic algal community present between 0.5-1.5 m water depth within this zone.

The transect sites and spot sites surveyed are shown in Figure 1.

2.2. Microscopic analysis

To determine the presence of *D. geminata* and to determine cell viability, microscopic analysis was undertaken on site. Three representative sub-samples were examined from each sample on a Leitz fluorovert FS inverted microscope at 100 – 400x magnification. Presence or absence, cell viability (as determined by condition of chloroplast) and relative abundance were recorded for *D. geminata cells.* Relative abundance was expressed as the percent of pooled sub-samples occupied by *D. geminata.*

3. Results

3.1. Lake survey

3.1.1. Shallow Bay

Macroscopic growths of *D. geminata,* containing viable cells with intact chloroplasts, were found growing attached to logs near the river mouth entrance into Shallow Bay. Drift mats of *D. geminata* were observed travelling into the lake moving along water currents derived from the Upper Waiau River. These drift mats were sampled to confirm the presence of viable cells entering the lake. *D. geminata* was found in 3 of the 20 benthic samples collected from Shallow Bay. All positive samples contained viable cells and were collected from near the lake entrance where river-derived current was present.

3.1.2. East of Richters Rock

Two *D. geminata* cells, one containing intact chloroplasts, were found in a single benthic sample collected from silt sediment on the east side of Richters Rock. *D. geminata* was not found to be present in the remaining 19 samples. Macroscopic growths of *D. geminata* were not observed in this area.

3.1.3. Frasers Beach

There were no macroscopic growths of *D. geminata* observed along Frasers Beach nor were any cells detected in benthic samples.

3.2. Zone 2 and 3

D. geminata was not found in any of the samples collected along the five transects or from the twenty spots samples collected within Zones 2 and 3 of the Waiau Arm.

3.3. Zone 1

Dead cells (defined as either empty frustules or with constricted chloroplasts) of *D. geminata* were found along Transects 29 and 30. Percent abundance was high with *D. geminata* contributing to 75% of the algal biomass present in samples (Figure 2). Two live cells were found in one sample collected from Transect 29. Dead cells were also found in over 50% of spot samples collected in Zone 1. Percent abundance ranged from 5 to 75% of the sample. In the shallow, cobbled area near the MLC, stalked material persisted attached to rocks with large accumulation of organic matter and bacteria on the stalks (Figure 3).

3.4. Aquatic algae and macrophyte community in Waiau Arm

Large blooms of filamentous green algae dominated the shallow water community within the Waiau Arm, accompanied by blooms of the diatoms *Synedra ulna*, *Tabellaria floculosa* and *Gomphoneis* sp (Figure 4). Deep-water communities were dominated by the cyanobacteria, *Oscillatoria* sp.

The native macroalgae *Chara corallina* and *Nitella hookeri* had re-colonised the silt substrate in the deepest parts of the arm forming lush meadows. In the lower part of Zone 1, native macrophytes *Potamogeton cheesemanii* and *Myriophyllum triphyllum* formed dense stands amongst the cobbled substrate (Figure 5). A thermocline was present in the Arm at the time of the survey, with temperatures in the upper 2.5 m reaching 13^{o}C and dropping to 8^{o}C with depth.

4. Discussion

While the presence of *D. geminata* in Shallow Bay is alarming, it is not unexpected. *D. geminata* is presently growing macroscopically in the Upper Waiau River. Natural downstream migration of sloughed off mats would typically be expected to reach the lake entrance and colonise suitable habitats. It is possible that this process may be further enhanced by recreational activities within the Upper Waiau River, such as fishing and jet boating. During the survey a commercial jet boat was observed moving from the river, through the lake entrance and across Shallow Bay (Figure 6). At the time of the survey all macroscopic growths of *D. geminata* in Shallow Bay were found in areas where flow (from water moving into the lake from the river) persisted. Two live cells detected in samples collected from the east side of Richters Rock were found on clay-type substrate. This substrate is typical of the shallow water zone of this area and would not support the growth of *D. geminata*. As there is no evidence to suggest that macroscopic growths of *D. geminata* persist in the immediate area, or in the entrance to the Waiau Arm for that matter, it is plausible to suggest that these cells were washed in or transported to this area from another site of infestation.

There does not appear to be a further upstream extension of *D. geminata* in the Waiau Arm since the August 2005 survey. Historically, upstream movement of *D. geminata* in the Waiau Arm was aided by the diversion of Mararoa River water up into the Arm. Adoption of the ‘park and flush’ regime now means that all water diversions from the Mararoa River have ceased. As water no longer moves towards the lake, this regime does not aid the dispersal of *D. geminata* upstream or into the lake. Upstream extension, or lake introduction, of *D. geminata* is now only possible through the assistance of other transport vectors, such as wind, fish, birds and human-mediated movement, or through re-introduction from other sites.

During the August survey blooms of *D. geminata* were found growing attached to rocks and submerged logs and loosely associated with bottom sediment and macrophytes in Zone 1 of the Waiau Arm (Sutherland et al. 2005). With the ‘parking’ of the Arm conditions were expected to be unfavourable for supporting the continuation of prolific growths of *D. geminata.* Results from the present survey indicate that this is indeed true, with approximately 99% of the *D. geminata* sampled consisting of dead frustules (Figure 2). Approximately 1/3 of the total frustules studied contained cellular material to some extent. This indicates that these cells had only recently died in the Arm, while completely empty frustules may have been dead for a long period of time.

The most likely explanation for the demise of *D. geminata* in the Arm is the reduction in supply of nutrients to the cells across the boundary layer. While the nutrient demands of *D. geminata* are not known they are likely to be relatively high due to the size of the frustules and the growth form that *D. geminata* takes. Algae that typically live attached to stream bottoms are able to assimilate only those nutrients in close proximity to the bottom and are reliant on water movement to renew their supply of nutrients. As the algal biomass increases zones of relatively stationary water (termed boundary zones) develop around and within the algal community, thus partially isolating the algae from the overlying flowing water. The size of these boundary zones is dependent on algal biomass and growth forms, as well as the velocity of the flowing water (Mulholland, 1996). The cessation of flow in the Waiau Arm would cause a reduction in the exchange of nutrients across the boundary layer surrounding *D. geminata.*

In a lentic environment, such as a lake and presently the Waiau Arm, complex nutrient interactions exist with many algae capable of sequestering nutrients from organic-rich sediments, from macrophyte hosts and from internal nutrient recycling within complex biofilms. The stalked growth form of *D. geminata* appears to severely limit its ability to acquire nutrients in this manner, as cells are not in direct contact with sediment, host macrophytes or form part of a complex biofilm. This, coupled with competitive demands from the spring growth of the resident algal population, may be the cause for the collapse of *D. geminata* since the August survey.

While these results appear to be a promising indication of whether *D. geminata* is able to thrive in lentic environments or not, caution must be advised when applying the results seen in the Waiau Arm to Lake Manapouri. Wave exposure and water movement is considerably greater in the lake than the arm, thus the potential for greater mass transfer of nutrients across boundary layers may allow *D. geminata* to thrive in wave wash areas of the lake. The lakewave exposure model of Lake Manapouri shows those areas that are considered most at risk to immediate infestation by *D. geminata* to have moderate to high wave exposure and water movement. Overseas, *D. geminata* has been observed colonising the wave-wash zone of lakes (Kilroy, 2004) but to date it has not been reported as problematic.

Since the 'parking' of water flow in the Waiau Arm, native macrophytes have proliferated in the shallow reaches of the Arm while native characeans have formed lush meadows in the deeper parts, increasing the overall health of the Waiau Arm.

5. Recommendations

The spring growth of resident algae in the Waiau Arm appears to be at the expense of *D. geminata*. Should the remaining viable *D. geminata* continue to survive in the Waiau Arm, it will either integrate into the algal community or could form a late season bloom following the collapse of the current resident algal bloom. In order to better understand the dynamics of *D. geminata* in the modified environment of the Waiau Arm, in particular with respect to a 'flushing' event, it is recommended that monthly monitoring of the algal community within Zone 1 be undertaken. At the time of the August survey live *D. geminata* constituted 100% of the algae present on rocks in the lower shallow reaches of the Waiau Arm (see Sutherland et al. 2005). This area is the most likely place *D. geminata* would first appear should re-growth occur. Periphyton within the lower shallow reaches of Zone 1 could easily be collected from

0.5 – 1 m depth range by wading, without the need for divers. Microscopic analysis would be used to determine the community composition.

Due to the decline of *D. geminata* in its most active growing site (Zone 1), the lack of evidence to suggest further upstream movement of *D. geminata* within Zone 2 coupled with the cessation of water movement upstream, further surveys in the Waiau Arm are not deemed necessary at this stage.

Monitoring of growth and extension of *D. geminata* within Shallow Bay, Lake Manapouri would be of interest to end users such as Guardians of the Lake, DoC, Fish and Game and Biosecurity NZ.

6. Acknowledgements

Greg Kelly and Neil Blair assisted with surveys and collection of benthic samples. We are grateful for the assistance provided by Mike Molineux in decontamination of sampling gear, SCUBA equipment, boat and vehicle.

7. References

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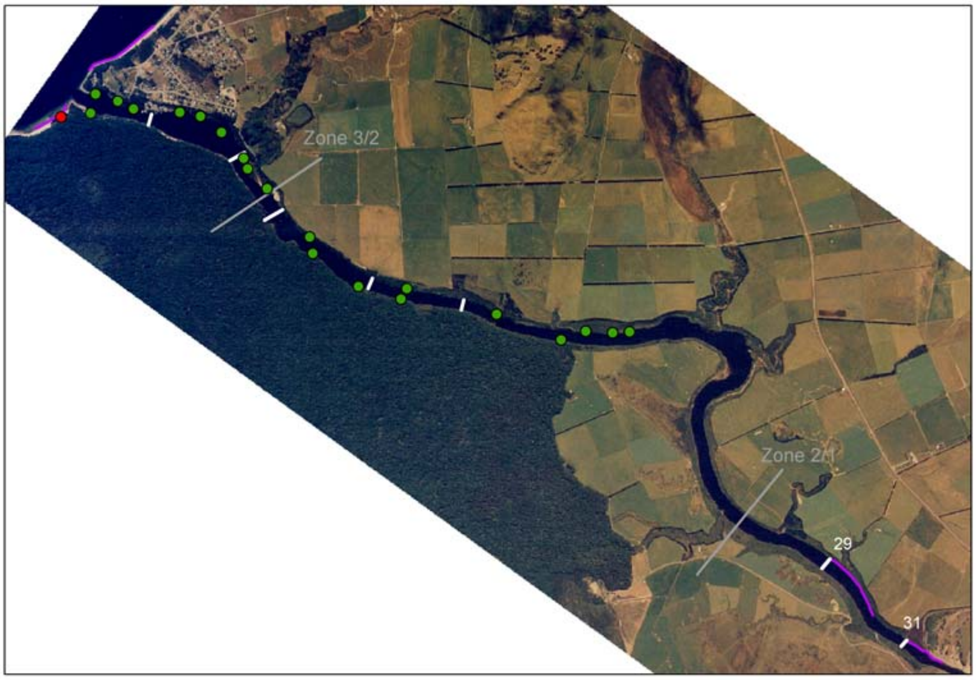

Figure 1a: **Map of Waiau Arm and Lake Manapouri showing transects (white bars), drift dive zone (purple bars) and spot (green dots) sampling locations. Positive site is marked by red dot.**

Figure 1b: **Map of Shallow Bay drift dive zone (purple bars). Positive site is marked by red dot.**

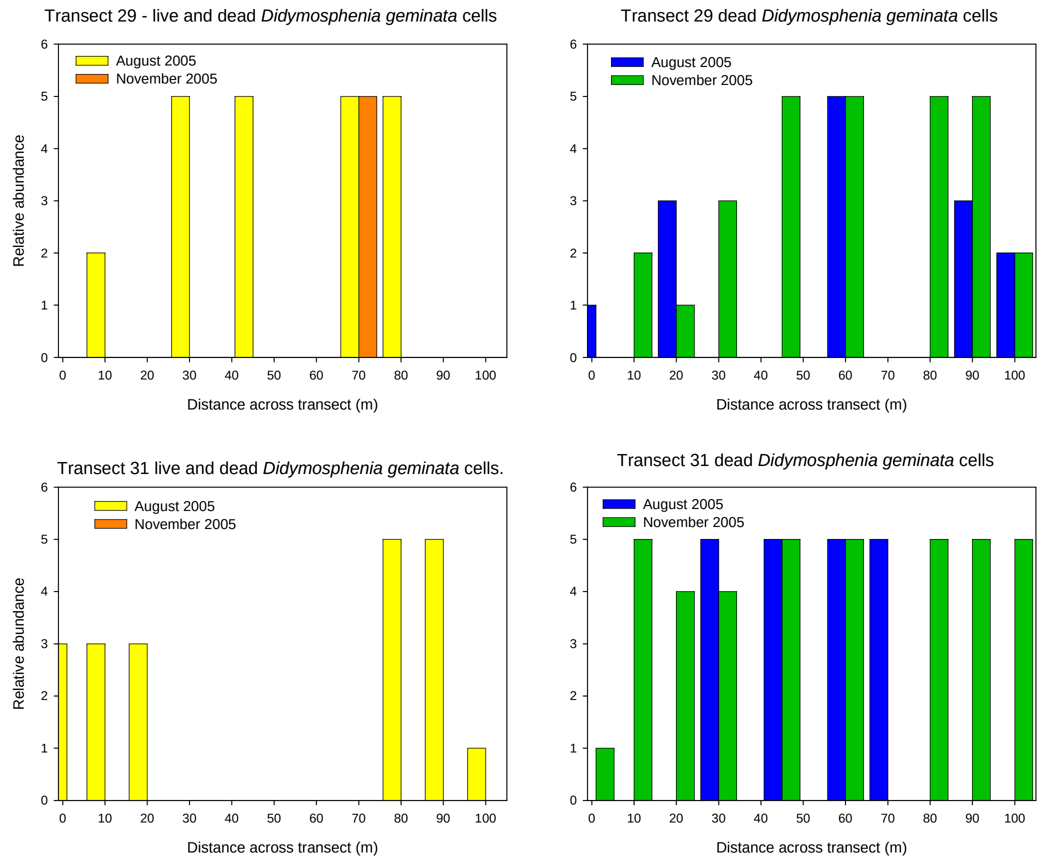

Figure 2. **Comparison of live and dead cells of *Didymosphenia geminata* located on transects 29 and 30 between August and November 2005 surveys.**

Figure 3: ***Synedra ulna*** **and** ***Tabellaria floculosa*** **dominated diatom community colonising rocks in the lower reaches of Zone 1. Old stalk material from** ***D. geminata*** **can be seen remaining attached to rocks after the cells have died (arrow).**

Figure 4: **Dense growth of resident algae attached to submerged braches in the Zone 1 of the Waiau Arm. This community was dominated by filamentous green algae and the diatoms** ***Synedra ulna, Tabellaria floculosa,*** **and** ***Gomphoneis*** **sp.** ***D. geminata*** **was not found to be present on this branch**

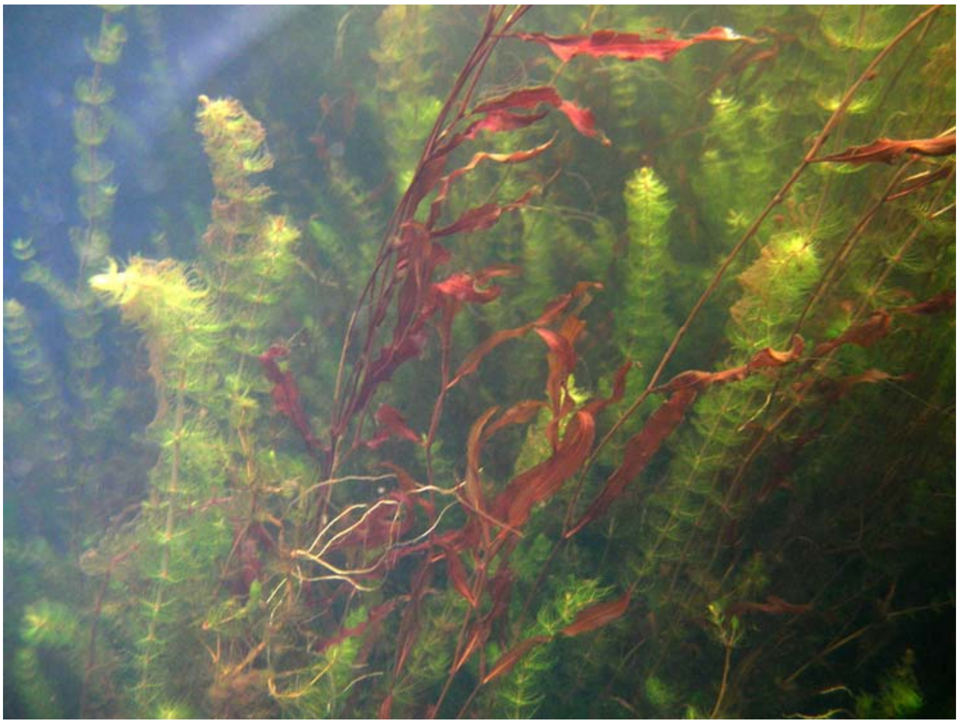

Figure 5. **Prolific growth of native macrophytes *Potamogeton cheesemanii* and *Myriophyllum triphyllum* in the lower shallow reaches of Zone 1.**

Figure 6. **Commercial jet boat moving across Shallow Bay, Lake Manapouri and back towards the Upper Waiau River.**