Department of Conservation
Te Papa Atawhai

A review of cage diving impacts on white shark behaviour and recommendations for research and the industry's management in New Zealand.

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Executive summary

Diving with sharks has become a significant and valuable adventure tourism activity in many regions of the world with estimated values to local economies ranging from USD 1.3 to 18 million. White shark cage-diving is one such industry that has developed in five jurisdictions: California, Mexico, South Africa, South Australia and New Zealand. As with many shark tourism industries, the white shark cage diving industry has generally developed in advance of local legislation to regulate it. However, experience emphasizes the importance of regulating shark cage diving in terms of both minimising the potential for impacts on sharks and the local environment, minimising potential risks to and conflict with other water users, as well as ensuring economic viability and industry harmony. As a result, white shark cage diving is currently subject to increasing controls across the jurisdictions within which it occurs.

White shark cage diving is a relatively new industry in New Zealand waters and some aspects of its management falls under the jurisdiction of the Department of Conservation (DOC). Although initially un-regulated, the industry in New Zealand has recently seen the introduction, in 2013, of a Code of Practice by DOC followed by the introduction of permits to operate in 2014. Furthermore, DOC committed to review the Code of Practice in 2016 to ensure that managing the New Zealand industry into the future was guided by experiences from other jurisdictions and the latest scientific knowledge on white sharks. This paper contributes to that process by providing a summary of white shark cage dive industries and their management world-wide, followed by a review of scientific literature of the impact of cage diving operations on white shark behaviour.

White shark cage diving around the world, including in New Zealand, occurs in areas where the species naturally aggregates with all current operations focussed around pinniped (seal/sealion) colonies. The industry takes advantage of the naturally higher local abundance of sharks and the reliability of more regular encounters at these sites, rather than attracting sharks to areas where they would not normally be.

Management of white shark cage diving is guided by specific management plans and various legislative and regulatory instruments in each jurisdiction within which it occurs. These regulations, in a traditional resource management sense, primarily focus on:

a) limiting effort (e.g. the number of operators)
b) spatial/temporal closures (restricting the activity to certain sites or zones and time periods), and
c) controls on equipment used or other operational restrictions.

A key regulatory driver is that white sharks are protected in all jurisdictions where cage diving currently occurs. In addition, three of the five areas world-wide where white shark cage diving takes place fall within marine protected areas. As a consequence, the management objectives relating to cage-diving operations generally reflect legislative requirements to minimise possible deleterious impacts on white sharks and/or requirements to minimise impacts on the local marine environment within conservation zones where cage-diving occurs.

Key elements for successfully managing white shark cage dive industries and minimising conflict between user groups include:

- a clearly articulated management plan and mandatory protocols for industry operation,
- limiting the number of licences to operate,
- restricting areas at which such operations take place,

- mandatory and effective reporting of industry activities and the collection of data on shark activity via a logbook system,
- establishing mandatory protocols that minimise impacts on sharks that may be detrimental to their well-being,
- establishing mandatory protocols that minimise the risk of conditioned behaviours in sharks,
- reducing overall impact on the environment and other species.

Management of shark cage diving in New Zealand now shares many aspects common to other jurisdictions including similar specifications on cage design to minimise potential harm to sharks, the handling of baits to minimise shark contact with cages, the use of chum and tethered baits comprising fish products only and prohibiting the presentation of baits from cages. All jurisdictions articulate an objective to minimise the intake of baits by sharks (with the exception of California where baiting in any form is prohibited). The objective of minimising the consumption of baits is to reduce the risk of either conditioning sharks in ways that may lead to changes in patterns of residency at cage diving sites, or deleterious impacts on sharks. The New Zealand Code of Practice is currently the most stringent for jurisdictions that allow baits to be used – specifically stipulating that sharks should not be allowed to consume baits, but, if this occurs then no further baits may be used on that day. Improving the efficiency and expediency of logbook reporting via the introduction of electronic logbooks has proven successful elsewhere (e.g. South Australia) and should be considered for the New Zealand industry. Despite evidence that conditioned behaviours are unlikely given the extent of rewards received by sharks under the current Code of Conduct (and in light of research pertaining to this topic elsewhere), such impacts cannot be unequivocally ruled out. Introducing a system of non-operator activity days as applied in South Australia may further reduce the risk of impacts to sharks in the Stewart Island area by interrupting regular contact between industry operations and individual sharks.

In line with legislation and management objectives, most research to date regarding shark cage diving operations has focussed on identifying behavioural responses to cage dive operations that may precipitate deleterious impacts on sharks. It is important to note that although studies on this topic refer to shark *behaviour*, all published studies have essentially been 'ecological' in their objectives with each investigating aspects relating to the *swimming behaviour* of sharks including swim speed, swimming depth, localised movements around cage diving sites, patterns of residency, habitat use and influences on broad scale movements/migrations. This has led to a 'popular' misinterpretation of research objectives and results whereby it has been assumed that where changes in behaviour have been studied and documented, they relate to sharks being conditioned to associate vessel and humans with food or become permanently more 'aggressive'. These aspects of shark behaviour have not been the subject of specific scientific investigation although the analysis of stimuli emanating from shark cage dive operations in South Africa concluded that such responses were unlikely.

A considerable knowledge-base on white shark ecology has emanated from research initiated around seal colonies including those where white shark cage diving occurs. In all cases, white sharks have been identified as temporary residents to such areas, usually showing elements of seasonal cycles to their presence and behaviour. Residency periods lasting from days to months generally alternate with long distance movements to areas often remote from these sites. Annual distances travelled are often of the scale of several 1000s of kilometres, in many cases including extensive open ocean excursions. White sharks are natural inhabitants of sites where cage-diving occurs, shark cage diving operations attract to the vessel sharks that are already within the general vicinity rather than attracting sharks from vast distances and data indicate that this activity neither permanently entrains sharks at sites of operation nor significantly influences their movements at either an annual time scale or broad spatial scale. However, a predictable response to shark cage dive operations is

influencing the movements of sharks at smaller spatial and temporal scales. The objectives of such operations are to attract sharks to within the visual range of observers on the vessel or an in-water protective dive cage and, where possible, extend contact time to enable clients to view sharks that would otherwise not be reliably seen. The most recent research suggests that the responses of sharks to cage dive operations can be complex and individually variable with not all sharks reacting in the same way where some may ignore cage diving operations whereas others may be more prone to responding.

Overall, it would seem unlikely that white sharks exposed to cage diving activities are any more or less likely to present a risk to divers, swimmers or surfers in areas away from cage diving sites than any other shark. Nevertheless, recreational and commercial in-water activities undertaken at sites where shark cage diving occurs, or in the immediate vicinity, carries considerable risk of shark encounters. Thus it is advisable that such activities are separated in time and space. It is, however, worth re-emphasizing that white shark cage diving operations take place specifically in areas where the species naturally occurs. As such, unprotected in-water activities in these areas carry a natural degree of encounter risk regardless of the presence of cage diving industry.

Research on movement patterns, habitat use and numbers of sharks utilising both the area around cage diving sites and the surrounding region are key components required to understanding the status of shark populations in the Stewart Island area and their interplay with cage diving operations. Although initial work has shed some insight into these areas, further research is suggested to define localised movement patterns and habitat use, local abundance and population size of sharks, as well as establishing a commercial fishing industry sightings register.

1 Brief and scope of this report

White shark cage diving is a relatively new industry in New Zealand waters where, similar to the early days of the industry's progress in other jurisdictions it initially developed with little formal regulation. Regulating white shark cage diving operations to ensure quality of industry product, client safety as well as minimising impacts on white sharks and their environment has become a common management focus in all jurisdictions where the activity now occurs. In New Zealand, management of the white shark cage diving industry falls under the jurisdiction of the Department of Conservation (DOC). December 2013 saw the initial introduction by DOC of the Commercial Great White Shark Cage Diving New Zealand Code of Practice (and all cage dive operators targeting white sharks in New Zealand waters have been required to obtain a permit from DOC since October 2014. The DOC committed to review the Code of Practice in 2016 as well as ensuring that the industry in New Zealand was regulated following the latest scientific knowledge and management experiences from other jurisdictions.

To aid this process, DOC commissioned the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia to provide a literature review addressing the following issues:

- Latest white shark behaviour research, with particular focus on cage diving interactions.
- Other shark species behaviour with regards to cage diving interactions, and other types of provisioning in ecotourism.
- Analysis and review of behaviour and conditioning reflexes and stimuli; i.e. conditioning to boat + cage vs. boat alone vs. divers/swimmers.
- Recommendations for future research on Stewart Island cage diving/sharks.
- Recommendations for management of cage diving industry at Stewart Island.
- Comparison of methods of operation between New Zealand, Australia, South Africa and Mexico white shark cage diving operations.

This report thus forms part of the DOC's overall review. It provides a summary of white shark cage dive industries and their management world-wide, followed by a review of the scientific literature on the impact of cage diving operations on white shark behaviour. It concludes with recommendations for research and management of the industry in New Zealand waters.

2 Introduction

2.1 Shark tourism and white shark cage diving

Diving with sharks has become a significant and valuable adventure tourism activity in many regions of the world with estimated values to local economies ranging from USD 1.3 to 18 million (Burgin and Hardiman 2015, Hammerschlag *et al*. 2012; Clua *et al*. 2011; Gallagher and Hammerschlag 2011; Orams 2002; Smith *et al*. 2010; Dicken and Hosking 2009; Topelko and Dearden 2005).

White shark cage-diving tourism is one such industry that has developed in five jurisdictions: California (Farallon Islands), Mexico (Guadalupe Island), South Africa (at five sites along 700 km of coast between False Bay and Algoa Bay), Australia (Neptune Islands) and New Zealand (Stewart Island) – Figure 1. The value of the Australian industry to the local Port Lincoln economy was estimated by Bradford and Robbins (2013) to be USD 4.75 million in 2011 and for South Africa by Hara *et al*. (2003) to be USD 3.1 million.

White shark cage diving occurs in areas where this species naturally aggregates and all current operations are focussed around pinniped (seal/sealion) colonies. These activities take advantage of the naturally higher local abundance of sharks and reliability of encounters rather than attracting sharks to areas where they would not normally aggregate. These areas generally have anchorages

suitable for cage-diving operations that provide the necessary sheltered conditions required to effectively operate. In most jurisdictions, cage-diving tours are primarily 'day-trip' in nature taking advantage of sites that are relatively accessible from local ports. Guadalupe Island in Mexico being the exception where multi-day trips are a necessity due to the offshore distance required to gain access to the site. One of the three operators working the Neptune Islands in South Australia also runs multi-day trips as part of an integrated wildlife experience that often combines shark cage diving with other wildlife viewing opportunities at either the same site or other areas in the vicinity.

White shark cage diving involves a range of operations and generates a variety of stimuli to which sharks may respond including actively chumming (= berleying), the presentation and consumption of tethered (= throw) baits, schools of finfish attracted to chum, in-water cages with divers, the general presence of the vessel and the associated physical, electrochemical and acoustic signatures of all of these components combined.

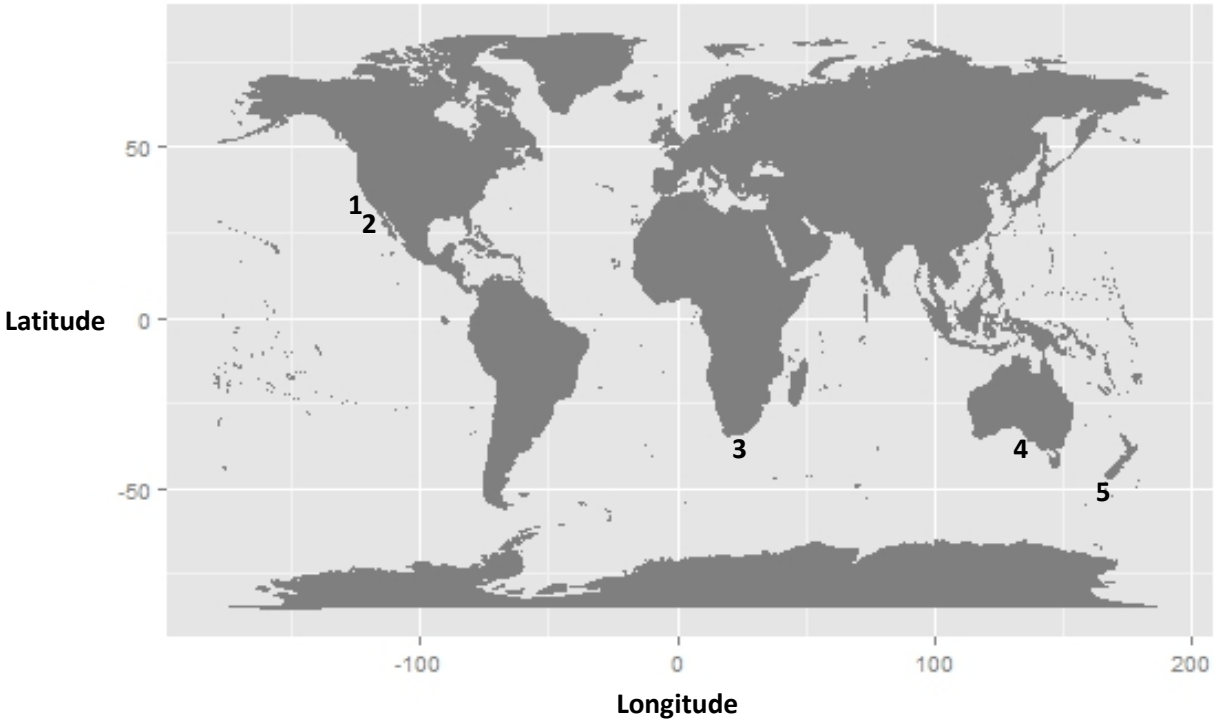

Figure 1: Location of shark cage diving industries. (1) California; (2) Mexico; (3) South Africa; (4) South Australia; (5) New Zealand.

2.2 Management of shark cage diving

In similarity to other forms of shark diving tourism, the white shark cage diving industry has generally developed in advance of local legislation to regulate it. However, it is currently subject to increasing controls across the jurisdictions within which it occurs with several jurisdictions currently reviewing their management controls and policies. These regulations, in a traditional resource management sense, primarily focus on:

d) limiting effort (e.g. the number of operators)
e) spatial/temporal closures (restricting the activity to certain sites or zones and time periods), and
f) controls on equipment used or other operational restrictions.

Specifically, these regulations include, in varying combinations, limiting the number of licences/permits to operate, restrictions on the location/number of sites where shark cage diving operations can occur, limitations on the number of days per year or season that cage diving can occur, limits on the type, number and/or amount of chum/tethered baits that may be used or lost to sharks and regulations regarding the use and design of specific equipment (e.g. towed decoys, dive cages, tethered bait lines) or client activities (e.g. touching of sharks and diving outside cages).

Further controls have also been imposed by industry codes of practice (either mandatory or voluntary) although the evolution of regulations in each area has generally seen a move to including codes of practice as mandatory conditions to operate under operator permits.

Management agencies in two jurisdictions, Guadalupe Island (Mexico) and the Farallon Islands (USA) have banned the use of all chum/berley used to attract white sharks – although operators at Guadalupe Island are allowed to use tethered baits (fish only) without limitation on size or number. Operators at the Farallon Islands are under the strictest limitations where both chum and any form of baiting (e.g. tethered baits) are banned. However, in this case, operators are allowed to use static floating decoys. Details of these operations and literature pertaining to them are summarised by jurisdiction below.

2.3 Rationale behind management regulations

It is important to note that white sharks are protected in all jurisdictions where cage diving currently occurs, including New Zealand waters. In addition, three of the five areas world-wide where white shark cage diving takes place fall within marine protected areas including the Neptune Islands Group (Ron and Valerie Taylor) Marine Park, Gulf of the Greater Farallones Marine Sanctuary and the Guadalupe Island Biosphere Reserve. The initial reasons for declaring these as protected areas were not primarily driven by their importance to sharks, although the importance of these areas to sharks is now generally recognised. Protection was initially instigated based on the significance of these sites to marine mammals and sea birds as well as their overall marine conservation values. Thus the management objectives relating to cage diving operations generally reflect legislative requirements to minimise possible deleterious impacts on white sharks due to their protected status (e.g. under Threatened Species, Environment Protection or Fisheries Acts) and/or requirements to minimise impacts on the local marine environment within conservation zones where cage-diving occurs, rather than any specific objective to minimise the risk of interactions between sharks and humans. For example, cage-diving free days (non-operator days) were introduced at the Neptune Islands in 2012 (DENR 2012, Smith and Page 2015) with the objective of minimising impacts on sharks, while chumming at Guadalupe Island was banned in 2013 specifically because of a regulatory requirement that prohibits the release of organic material into the Guadalupe Biosphere environment rather than for a specific objective to minimise impacts on either sharks or other water users (Aguilar *et al.* 2015, O. Sosa-Nishizaki, CICESE pers. comm. 2015).

Nevertheless, objectives to minimise the impact of cage diving activities on shark behaviour are becoming more entrenched in management plans for the industry across most jurisdictions. One jurisdiction, South Australia, has proposed a framework that explicitly relies on monitoring to assess the efficacy of regulations designed to minimise specific impacts on sharks combined with a feedback loop requiring additional management actions should defined trigger points be breached (Smith and Page 2015). Other jurisdictions have generally adopted various measures to minimise impacts on white sharks and/or the environment but do not specifically identify a means to assess the efficacy of these measures. The latter can represent an impediment to effective management and monitoring of the industry and can reduce public confidence in such management objectives and the efficacy of management actions.

3 Summary of cage dive operations and management by jurisdiction

Management of white shark cage diving is guided by specific management plans and various legislative and regulatory instruments in each jurisdiction within which it occurs. However, the style of operations and management details of the industry varies between jurisdictions. The following section provides a brief description of each jurisdiction's cage dive operations and the corresponding management arrangements. Management arrangements and regulations are tabulated in Appendix 1.

3.1 South Australia

White shark cage diving in Australian waters is currently only permitted within the Neptune Islands Group (Ron and Valerie Taylor) Marine Park in South Australia. The Neptune Islands are located in mid-shelf waters approximately 60 km south of Port Lincoln and approximately 30 kilometres from the mainland coast. The remote location helps to reduce conflict with other marine-based activities. Operations are permitted at both the North Neptune Islands and South Neptune Islands which are located 12 km apart. There are no restrictions on where at these locales that cage diving can be undertaken. However, activity is typically restricted by weather conditions and the corresponding suitability of a limited number of anchorages.

3.1.1 Description of operations

Shark cage diving at the Neptune Islands is restricted to three licensees and is based on two business models – regular day-trips to the site (two operators) and extended multi-day trips that that often combines shark cage diving with other wildlife viewing opportunities. The latter, offered by one operator, may include a variety of other sites. Two operators are permitted to use chum and tethered baits to attract sharks. A third operator uses acoustic attraction methods and is restricted to that technique. Chum and baits are restricted to fish products only.

Vessels are anchored during operations and sharks are either viewed from the deck of the vessel or from an in-water dive cage. Two operators use surface-based cages; one operator also specialises in subsurface cage diving where the cage is lowered to the sea floor. No decoys (towed or static) are permitted.

Operators are required to complete daily logbooks recording the timing and location of operations, the volume of chum dispensed, and various details of sharks sighted. Historically logbooks were paper-based, but this was changed to an electronic system introduced in 2013 based on iPads and the on-line Fulcrum™ application (Rogers *et al*. 2015; see http://www.fulcrumapp.com/).

3.1.2 Management arrangements

Major policy changes were introduced in 2012 (DENR 2012) after research detected changes in the residency times of white sharks at the Islands and their diel occupancy of cage diving sites subsequent to a significant increase in operator effort post-2007 (Bruce and Bradford 2013). These policy changes sought to minimise further impacts on white sharks by managing cage dive tourism effort. As a result, the industry was capped at a maximum of three licences to operate, two exemptions to use berley and restricted to one vessel per licence.

Cage diving activities occur year-round at the Neptune Islands. However, the number of days when shark cage dive operations are permitted is currently limited to 10 days in any fortnight (termed 'activity' days) so as to provide regular operation-free days at the site where sharks are not exposed to cage diving activities. A consensus agreement is achieved between cage dive operators and the managing agency to determine which days are deemed operator-free. Licences are currently granted for periods of five years. Both a Commercial Tour Operators licence from the Department of

Environment Water and Natural Resources (DENR 2011) and an annually renewable authorisation to berley from Primary Industries & Regions South Australia are currently required.

The South Australian Government is currently working with licensees and other partners to amend regulations relating to berley use, develop an updated policy for the activity and offer new licences that will reflect these conditions with the following under current consideration.

- A proposed amendment to regulations for the use of berley and bait will extend the term of berleying authorisations from one year to five years.
- An updated policy for the activity is being developed to:
  - consolidate licences to operate and permission to use berley into a single licence.
  - establish limits on bait and berley use.
  - embed an adaptive management approach based on the ongoing monitoring of mean shark residency into licensing arrangements.

New licences will be offered to existing operators to extend current 5 year licences to a 10 year term and will incorporate the updated policies outlined above.

South Australia is currently the only jurisdiction that has proposed a policy to monitor the efficacy of management initiatives to reduce impacts on sharks. Significantly, the proposed policy would provide an adaptive management framework with defined trigger points for further management action should there be evidence (based on the residency metrics of sharks) for an increased level of impact or a return towards a predetermined residency baseline (Smith and Page 2015). The proposed policy is based on residency patterns determined from the acoustic tagging of sharks subsequently monitored by subsurface acoustic receivers. Data from 2001-2003, prior to the expansion of industry activity in 2007, define the reference period. The proposed policy would allow for a graded management response depending on the difference between the measured average residency of tagged sharks compared to the reference period while taking into consideration the natural variation likely to occur in this metric between years. It will allow for management measures (e.g. the number of activity days, limits on tethered bait and chum usage) to be increased or relaxed depending on the level and direction of measured change. This would require ongoing monitoring and tagging of sharks to achieve goals and is underpinned by extensive previous data on shark residency and movement patterns at the Neptune Islands – conditions that are rarely met within other cage diving jurisdictions.

3.2 South Africa

South Africa has the most extensive white shark cage dive industry in terms of both number of operators and the number of sites where the industry is allowed to operate. Shark cage diving is permitted at five sites along 700 km of coast between Cape Town and Port Elizabeth. Specific sites where operations are permitted are Seal Island, False Bay, Dyer Island, Gansbaai, Quoin Rock, Quoin Point; Seal Island, Mossel Bay and Algoa Bay, Port Elizabeth (GN-R724 2008). Dive sites are typically close to shore (< 10 km), Seal Island at Mossel Bay is only 700 m offshore from the nearest populated centre.

3.2.1 Description of operations

Shark cage diving in South Africa occurs relatively close to the mainland coast and is based on a day-trip basis. Vessels are relatively small compared to South Australia, Guadalupe Island and The Farallons where the greater distances and sea conditions dictate the use of larger vessels. Some operators are permitted to use towed decoys to elicit breaching behaviour in sharks and operations either combine such activity with cage diving or run cage diving trips alone. Cage-diving is all surface-

based and cages are required to be fixed to the attending vessel by rope and at no more than 300 mm from the cage dive vessel.

Operators are required to complete paper-based logbooks recording the timing and location of operations, the various details of sharks sighted and dive operations. Facsimile copies of logbooks are submitted monthly to the managing authority.

3.2.2 Management arrangements

Although there are no specific limits on the number of permits that can be issued, the governing management policy specifies that the number of permits should be informed by precautionary management that is flexible to allow feedback from scientific studies. The management policy also identifies a specific objective to promote the economic growth of the white shark cage diving industry and the sustainable non-consumptive use of white sharks particularly for tourism through the allocation of the optimal number of permits that can be safely issued (GN-723 2008). The policy further stipulates that the number of permits issued should be controlled in order to manage any adverse impact on white shark behaviour and to protect white sharks – although the means to assess this is not stipulated. There were 12 licensed operators in 2008 and up to 14 operators have been active in the industry since. Operators may register two vessels but can only use one at any given time. Annual permits may be re-allocated for up to five years (as of 2010) provided operators have a full history of compliance with permit conditions (GN-R724 2008).

The period of operations is not restricted with the exception of Seal Island at Mossel Bay and Quoin Point where operations are not permitted during the summer holiday period from 1 December to 20 January the following year (GN-R724 2008).

Similar to other jurisdictions, chum and tethered baits are restricted to fish-based products with a maximum daily limit of 25 kg. Bait handlers must not encourage sharks to ingest baits and sharks are not allowed to be intentionally fed. Presenting baits from cages is not permitted. Vessels must carry an active vessel monitoring system (VMS) that logs position every five minutes (GN-723 2008).

Provisions exist for operators to tow decoys to elicit breaching behaviour in sharks (GN-R724 2008).

3.3 Mexico

Shark cage diving in Mexico is only permitted within the Guadalupe Island Biosphere Reserve some 260 km off the mainland coast. Guadalupe Island is approximately 35 km in length and cage diving operations are specifically restricted to a 6km stretch of coast (607 ha area) on the northeast side of the island to minimise impacts on white sharks, by providing areas where sharks reside without being exposed to operations, and for ease of compliance monitoring.

3.3.1 Description of operations

Due to the large distance from the nearest port, white shark cage diving is based on multi-day trips to the site. All vessel operators are required to inform the Mexican Navy of the dates of arrival and departure from the Biosphere Reserve. There are six operators. Surface-based dive cages are suspended from the stern of the attending vessel and a maximum of four divers are permitted in a cage at any one time (Aguilar *et al.* 2015).

Operators are required to complete paper-based daily logbooks recording the timing and location of operations, the volume of chum dispensed, and various details of operations and sharks sighted. Reports are submitted on a trip by trip basis and an annual season report is also submitted to the managing authority (Aguilar *et al.* 2015, O. Sosa-Nishizaki, CICESE pers. comm. 2015).

3.3.2 Management arrangements

There is no specific limit to the number of permits that may be issued for cage diving activities but the current number issued is six. Permits are issued for a two year period. There are currently no restrictions on the time of year when operations occur, but various management arrangements are currently under review.

Guadalupe Island is one of two jurisdictions where chum/berley is not permitted during cage dive operations. However, tethered baits (local fish products only) are permitted and there is no limit to the number of baits that can be consumed by sharks. Baits cannot be offered from the dive cage. Operations are defined by a formal Code of Conduct (Aguilar *et al.* 2015). Neither use of decoys nor methods of acoustic attraction of sharks are permitted.

3.4 California

Shark cage diving in California is only permitted at the Farallon Islands approximately 45 km off the coast west of San Francisco.

3.4.1 Description of operations

Commercial operations at the Farallon Islands are primarily based on day trips. Vessels either anchor using tethered decoys to attract sharks for clients to view from the vessel or an in-water cage, or patrol the island area looking for natural predatory events. Mandatory paper-based logbooks are completed and records are submitted at the end of each season. White sharks are typically seasonal in their presence at the Farallon Islands with the best viewing period running from September through November each year. This timing dictates the main schedule for shark cage dive operations (NOAA 2014).

3.4.2 Management arrangements

Operations at the Farallon Islands are under the strictest arrangements with respect to permitted activities of any jurisdiction, only allowing tour operators to attract sharks with decoys (no chum or bait). There have been two to four vessels actively operating white shark tours since 2009. Operators are only permitted to use artificial decoys made of soft materials (excluding Styrofoam) tethered to an anchored vessel. No chum or baiting is permitted and decoys cannot be towed behind a moving vessel. Operators are able to view natural predatory events but cannot approach within 50 m of a white shark when doing so. In addition every vessel must have a trained naturalist on board (NOAA 2014).

3.5 New Zealand

White shark cage diving primarily occurs at Stewart Island located immediately south of the South Island of New Zealand, although some cage diving targeting white sharks has previously occurred at the Chatham Islands off the east coast.

3.5.1 Description of operations

Two operators currently run shark cage diving on a day trip basis where they return to port after the day's activities even if returning to the cage dive site with the same clients the following day. Activities are confined to within 300 m of Edwards Island off the coast of Stewart Island. Operations are seasonal, running from approximately December to May.

3.5.2 Management arrangements

Management of shark cage diving in New Zealand shares many regulatory aspects initiated under other jurisdictions including similar specifications for dive cage design (Maritime New Zealand 2014), the handling of baits to minimise shark contact with cages, the use of chum and tethered baits comprising fish products only and prohibiting the presentation of baits from cages. The New Zealand

Code of Practice prohibits the use of decoys in any form, specifically stipulates that chum must be finely minced with neither chum nor baits suspended from the vessel in bags or containers.

All jurisdictions articulate an objective to minimise the intake of baits by sharks (with the exception of the Farallon Islands where baiting in any form is prohibited). However, the New Zealand Code of Practice is the most stringent for jurisdictions that allow baits to be used – specifically stipulating that sharks should not be allowed to consume baits, but if this occurs then no further baits may be used on that day. Typically it is difficult to eliminate the chances of baits being taken by sharks when they are presented, although trained rope handlers can minimise this from happening. The objective of minimising the consumption of baits is to reduce the risk of conditioning sharks via such rewards (see below).

Other conditions imposed include prohibiting the use of acoustic attraction devices and a prohibition on divers touching or attempting to touch passing sharks from the cage.

4 Review of research on interactions between white sharks and cage-diving operations

Five published studies have specifically examined white shark behaviour in response to shark cage diving (Bruce *et al*. 2005, Johnson and Kock 2006, Laroche *et al*. 2007, Bruce and Bradford 2013 and Huveneers *et al.* 2013). In line with legislation and management objectives, most research to date regarding shark cage diving operations has focussed on identifying if there is evidence for behavioural responses that may precipitate deleterious impacts on sharks.

It is important to note that although studies on the responses by sharks to cage diving operations refer to shark *behaviour*, all published studies have essentially been 'ecological' in their objectives with each investigating aspects relating to the *swimming behaviour* of sharks including swim speed, swimming depth, localised movements around cage diving sites, patterns of residency, habitat use and influences on broad scale movements/migrations. This has led to a 'popular' misinterpretation of research objectives and results whereby it has been assumed that where changes in behaviour have been studied and documented, they relate to sharks being conditioned to associate vessel and humans with food or become permanently more 'aggressive'. These aspects of shark behaviour have not been the subject of specific scientific investigation although there are indications from some studies that changed behaviours along these lines are unlikely (see below). There are also comparatively few data regarding the extent to which cage diving activities may lead to impacts on the local environment or species assemblages (e.g. finfish, other sharks and rays) at such sites although anecdotal observations on increases in the abundance of finfish at cage dive sites suggests this may be an important effect to consider.

4.1 How does shark cage diving influence movement patterns, residency and habitat use?

Although relatively few studies have specifically examined the response of sharks to cage diving activities, a considerable knowledge-base on white shark ecology has emanated from research initiated around seal colonies where white shark cage diving occurs. This includes some of the most extensive studies conducted to date on movement patterns and behaviour. Research at these sites has also more recently explored estimating local population sizes and shark physiology (Chapple *et al.* 2011, Semmens *et al*. 2013, Towner *et al*. 2013). The co-location of research and shark cage diving is primarily driven by the natural accessibility of sharks afforded at these localities. In some instances, shark cage diving operations also provide key opportunities as platforms for research activities or data collection in the form of tagging and sampling as well as providing information from data recorded in industry logbooks. One of the consequences of these combined activities is that the movements and behaviour of white sharks at areas around seal colonies and shark cage diving sites in particular are some of the best studied of all habitats occupied by the species.

Research at sites where shark cage diving occurs initially focussed on predatory behaviour and localised movements as well as general biology and ecology (e.g. Klimley 1994, Ainley *et al*. 1985, Strong *et al*. 1996, Klimley *et al*. 2001, Martin *et al*. 2005). However, the development of electronic tags enabling researchers to track the movement of sharks has seen a rapid shift towards research focussed on movement patterns across a range of spatial and temporal scales. This has included sharks' use of habitats both in the vicinity of the specific seal colony where tags are deployed, occupancy of sites more distant and their overall swimming behaviour. The spatial and temporal scales of these studies have changed over time concomitant with the technological advances of tags that have allowed researchers to track white sharks over progressively longer time periods and distances at one extreme (Boustany *et al*. 2002, Bruce *et al*. 2006, Weng *et al*. 2007, Domeier and Nasby-Lucas 2013, Francis *et al*. 2015), to exploring the fine scale three dimensional movements of sharks at the other (Huveneers *et al*. 2013). Most recently such data has improved knowledge of the feeding requirements of the species (Semmens *et al*. 2013).

There are numerous commonalities in white shark behaviour and movements recorded across pinniped colonies in general and cage-diving sites in particular. In all cases, white sharks have been identified as temporary residents to such areas, usually showing elements of seasonal cycles to their presence and behaviour. Residency periods lasting from days to months generally alternate with long distance movements to areas often remote from these sites. In nearly all cases studied, most sharks spend considerably less of their annual regime specifically in the vicinity of seal colonies (and thus shark cage dive operations) than they do travelling to, or being resident in, different habitats where the availability of prey other than seals dominates (for example moving from temperate seal colony sites to tropical areas). This is an important factor when assessing the impact of shark cage diving on sharks as individual exposure to cage diving activities is restricted to those times of the year when sharks are temporarily present at cage diving sites. Annual distances travelled are often of the scale of several 1000s of kilometres, in many cases including extensive open ocean excursions. Sharks tagged at the Farallon Islands and Guadalupe Island have been regularly tracked moving into a broad area of the eastern Pacific centred approximately 1500 km from shore and as far west as the Hawaiian Island chain (Boustany *et al*. 2002, Weng *et al*. 2007, Jorgensen *et al*. 2009, Nasby-Lucas *et al*. 2009). Sharks tagged in South Africa at shark-cage dive localities have been tracked as far east as northwest Western Australia and return (Bonfil *et al*. 2005). Time spent in such offshore zones can vary between sexes and life history stages with, for example, adult females spending up to 18 consecutive months in offshore areas of the eastern Pacific with a biennial return to inshore zones, whereas males tend to show a more regular annual pattern of inshore return (Domeier and Nasby-Lucas 2013).

While showing some seasonal level of predictability, the broad scale movements of sharks to and from sites where shark cage diving occurs are not always coordinated between individuals, with arrivals and departures occurring over extended periods. Significantly, departures of individual sharks occur even in the continued presence of shark cage dive operations. This is particularly apparent at the Neptune Islands in South Australia where sharks continue to depart on long-distance movements into the western Great Australian Bight and to as far as northwest Western Australia despite the year-round presence of shark cage dive operations. In New Zealand waters, white sharks tagged near Stewart Island have been tracked moving to areas as far afield as New Caledonia, Vanuatu and eastern Australia (Duffy *et al*. 2012), with some individuals showing annual returns and similar long distance movements in successive years (Francis *et al*. 2015). The overall movements of sharks tagged at sites where cage-diving regularly occurs are similar to movements of sharks tagged in areas either subject to only sporadic cage diving operations or where this activity is not permitted. Sharks tagged at inshore areas of Ano Nuevo Island, Point Reyes and Tomales Point in California (where cage diving is not permitted) have similar seasons of residency and offshore movements to

those tagged at the Farallon Islands and sharks tagged at the Chatham Islands in New Zealand, where there has been only irregular shark cage diving activity, also travelled as far afield as New Caledonia (Bonfil *et al*. 2010) similar to the extent of movements of sharks tagged at Stewart Island (Francis *et al*. 2015). White sharks are thus natural inhabitants of sites where cage-diving occurs and these data indicate that this activity neither permanently entrains sharks at the sites of operation nor significantly influence shark movements at either an annual time scale or broad spatial scale.

However, a predictable response to shark cage dive operations is influencing the movements of sharks at smaller spatial and temporal scales. Indeed, temporarily influencing the swimming patterns of sharks is one of the key elements of a successful and economically viable shark cage-diving operation and an essential element for client satisfaction (Bruce and Bradford 2013). The objectives of such operations are to attract sharks to within the visual range of observers on the vessel or an in-water protective dive cage and, where possible, extend contact time to enable clients to view sharks that would otherwise not be reliably seen. The localised behaviour of white sharks in response to cage diving operations has been examined to date at sites in South Africa and South Australia. Bruce and Bradford (2013) noted that the centre of white shark activity shifted between sites at the Neptune Islands in response to the location of active shark cage diving operations. At the same location, Huveneers *et al*. (2013) found that sharks on average swam in a more limited area focussed around shark cage dive vessels and at shallower depths when chumming took place than for the same area on days when no operators were present. These results were similar to Laroche *et al*. (2007) who also noted that sharks swam at significantly shallower depths in the vicinity of a vessel undertaking chumming operations at Seal Island in South Africa when compared to other areas around the island. These authors also observed a propensity for acoustic-tagged sharks to be more commonly detected by receivers closest to the site where chumming took place.

The spatial scale over which chum/berley can attract white sharks during cage dive operations has only been examined by one study. Strong *et al*. (1996) concluded that the experimental chum trail they used (similar in nature to that used by most current operations) was unlikely to attract sharks from more than a few kilometres and that this was highly dependent on local wind and water currents. The general consensus is that shark cage diving operations only attract to the vessel sharks that are already within the general vicinity rather than attracting sharks from vast distances. This is indirectly supported by the frequency that no sharks are sighted during shark cage dive operations at some sites despite extensive chumming operations.

Despite these observations, evidence suggests that the responses of sharks to cage dive operations can be complex and individually variable (Johnson and Kock 2006); not all sharks react in the same way and some appear to ignore such operations altogether. Huveneers *et al*. (2013) noted that some sharks detected by an acoustic receiver array did not approach operator vessels that were actively chumming and some only visited the cage dive site when vessels were absent. Laroche *et al*. (2007) also noted that tagged sharks were observed at a vessel undertaking chumming on only 36% of the occasions that they were concurrently detected around Seal Island. While some of these responses may be influenced by dominance hierarchies in sharks present around cage diving vessels (Strong *et al*. 1996), it illustrates that not all sharks present in an area where cage diving occurs are similarly responsive to these operations.

Although research has demonstrated local short term spatial and temporal responses by some sharks to cage diving operations, determining the extent to which such responses persist by influencing long-term patterns of movements and habitat use has been impeded by a lack of baseline data on shark abundance, behaviour and movement patterns prior to the commencement of a cage diving industry at these sites. The North Neptune Islands in South Australia, however, saw an expansion in shark cage-diving activities during 2007, with the mean annual number of days when

operations occur rising from an average of 67 days prior to 1997 to a maximum of 287 days in 2011 (Bradford and Robbins 2012) with average annual effort more than doubling from 124 days (2000 – 2006) to 265 days (2008 – 2011), Bruce and Bradford (2013). This rapid and sustained increase in effort also coincided with a change from irregularly-timed, multi-day trips with irregular operator periods prior to June 2007, to a more regimented, near-daily operation with cage-diving activities occurring over a regular timed daily schedule thereafter. Bruce and Bradford (2013) used data from 47 acoustic tagged sharks (26 tagged from 2001 to 2003 and 21 tagged from 2009 to 2011) and industry logbook records to compare a series of behavioural metrics before and after this rise in industry effort and regularity of operations at the Neptune Islands. This study demonstrated that after 2007 there were significant increases in the number of sharks reported by cage-dive operators, an increase in the residency period of sharks (the period sharks were present in the overall North Neptunes area), increases in the duration of visits (consecutive days detected at the cage diving site) and a change in diel behaviour whereby the local daily arrival and departure of sharks at the specific cage-dive site became aligned with the daily schedule of cage dive operations. These changes were specific to the location of cage-diving operations (North Neptune Islands) and were not observed in sharks at a nearby pinniped colony only 12 km distant (South Neptune Islands). It should be recognised, however, that although differences were statistically significant, the measured changes were relatively small. For example median residency periods increased from 4 days (range 1 to 52) during 2001 – 2003 to 9 days (range 1 to 92) during 2010 – 2011 and the median duration of visits increased from 2 to 4 days over the same periods. Nevertheless this study concluded that cage diving operations had contributed to a long-term change in the way sharks utilised the North Neptunes Islands. These observed changes were also the catalyst for introducing management measures to restrict cage diving effort and monitor residency patterns to assist in assessing the efficacy of management actions to reduce impacts on sharks and guide future management needs (Rogers *et al.* 2014, Smith and Page 2015).

4.2 Behaviour and conditioning to vessels and implications for divers/swimmers

A typical conditioned response, whereby an animal is either deliberately or inadvertently trained to respond, generally requires consistent exposure to a specific stimulus and a reward for doing so. Shark cage diving provides a vast range of stimuli that sharks may respond to including the odour corridor provided by the chum/berley trail, the presence of tethered baits, the cage diving vessel itself, a variety of fish (sometimes in high abundance) attracted to feed in the chum/berley trail, the dive cage with divers and the variety of visual, acoustic and electrochemical cues (e.g. vessel anodes and other dissimilar metal combinations and natural electrical fields) associated with all of these. Chum/berley, where permitted in jurisdictions allowing cage diving, is limited in each case to fish products only and typically consists of finely minced fish (e.g. tuna) and fish oil/blood, commonly with a limit on the amounts permitted. Chum/berley provides an odour corridor which sharks can detect and follow to its source. Chum/berley as used in shark cage dive operations provides an attractant bringing sharks to the vessel that are already present in the general vicinity (Strong *et al.* 1996) but by itself provides no tangible reward to sharks and thus, by itself, is unlikely to result in conditioning. The finely minced fish and blood/oil products are too small for sharks to feed on and gain reward. However, the chum/berley trail has the potential to provide significant reward for smaller finfish at cage diving sites. Thus the only specific reward available to sharks from cage diving operations are tethered baits used to bring sharks within close proximity to the cage diving vessel.

Laroche *et al*. (2007) specifically examined the response of sharks to a vessel during chumming operations that also presented tethered (= throw) baits at Seal Island in False Bay, South Africa. These authors reported a nearly ubiquitous trend whereby the observed time spent around the vessel decreased with days of exposure to chumming operations. They noted, however, that some sharks were more successful at taking tethered baits than others. These authors thus specifically examined the response patterns of these sharks as they were more likely to show conditioned

behaviour after gaining the most reward. However, data from these sharks too indicated a trend of decreasing response to chumming operations with days of exposure despite their procurement of baits. These results were contrary to that expected if sharks were being specifically conditioned to shark cage dive activities and demonstrated that sharks may progressively reduce responses to operations after periods of time even with reward received in the form of tethered baits. A reduction in response by way of reduced time at the cage diving vessel and reduced motivation to procure baits is also commonly observed at the Neptune Islands (A. Fox pers. comm., author's observations). Laroche *et al*. (2007) also compared the responses of sharks to a vessel when it was engaged in chumming operations to days when a vessel was not. They found that sharks rarely visited the vessel when chumming was not in operation and on the occasions they did so, contact time was very brief. This was despite using the same vessel in chumming/no chumming trials and in the same locations, a situation likely to maximise the likelihood of sharks responding. These authors concluded, for at least the conditions they investigated, that moderate levels of chumming and the consumption of baits had only minor effects on the behaviour of sharks and would be unlikely to result in long term conditioning and behavioural change.

Similar results were also reported by Johnson and Kock (2006) for Gansbaai and Mossel Bay, also in South Africa, whereby sharks spent progressively less time at cage diving vessels with increasing days of exposure. Johnson and Kock (2006) also noted that a small subset of sharks were more prolific at consuming baits and notably these sharks showed some evidence of possible conditioning whereby they progressively arrived more quickly at the cage dive vessel over consecutive days of exposure. These authors suggested that sharks may more frequently move towards the site in anticipation of the cage dive vessel's presence. An anticipatory response to the arrival of cage diving vessels was also suggested by Bruce and Bradford (2013) who observed that the arrival times of white sharks at a cage dive site at the Neptune Islands became aligned with the timing of arrival of cage diving vessels and that this pattern persisted even on days when cage diving vessels were not present. Similar anticipatory responses in other shark and ray species have been demonstrated in whip rays (Gaspar *et al*. 2008), bull sharks (Brunnschweiler *et al*. 2014), black rays (Newsome *et al.* 2004) and white tip reef sharks (Fitzpatrick *et al*. 2011). Such responses when recorded, however, have been highly localised to the specific dive sites where operations occur and such changes in behaviour have not been recorded for sharks observed at nearby sites. However, both Johnson and Kock (2006) and Bruce and Bradford (2013) concluded that limiting the number of baits taken by white sharks during cage dive operations was likely to reduce the potential for such responses.

Johnson and Kock (2006) also considered the potential for sharks exposed to cage diving to subsequently pose an increased threat to human safety in other areas due to a conditioned response to these operations. They argued that the main stimuli of shark cage diving operations was sufficiently dissimilar to that provided by a swimmer or diver alone to render it improbable that sharks exposed to cage diving would then associate swimmers and divers with such stimuli. A similar conclusion was reached by Meyer *et al*. (2009) with respect to cage diving with sharks (Galapagos, sandbar and tiger sharks) approximately 5-6 km off the coast of Ohau, Hawaii. Such conclusions have merit when considering that the range of visual, olfactory, acoustic and electrochemical signatures associated with shark cage diving operations likely preclude sharks from specifically focussing on a human form inside a dive cage when exposed to these operations and specifically when responding, in many instances, to what seems to provide a limited reward. Given these observations, combined with the multiple stimuli provided by shark cage-dive operations overall, it would seem unlikely that white sharks exposed to cage diving activities are any more or less likely to present a risk to divers, swimmers or surfers in areas away from cage diving sites than any other shark.

Nevertheless, recreational and commercial in-water activities undertaken at sites or in the immediate vicinity of where shark cage diving occurs carries considerable risk of encounters with

white sharks, some of which may be temporarily stimulated by their exposure to such operations. Thus it is advisable that such activities be separated in time and space. It is, however, worthy of emphasis that white shark cage diving operations take place specifically in areas where the species naturally aggregates. As such, unprotected in-water activities in these areas carry a natural degree of encounter risk regardless of the presence of cage diving operations.

4.3 Other factors

An additional factor often not considered when interpreting the impact of shark cage diving on shark behaviour is that white sharks can be exposed to other, sometimes regular, interactions with human activity across their local range. Some of these also present inadvertent 'rewards' to sharks and have the potential to provide a cumulative behavioural effect including 'unsolicited' approaches to vessels. In many cases, these interactions have occurred over many decades including, but not restricted to, fishing operations where sharks are attracted to hauling of trawl nets, harvest of farm-caged finfish, depredation of fish caught on commercial and recreational line fishing gear (including longline, dropline and handline) and other recreational fishing activities including chumming to attract finfish or other shark species. This can be particularly prevalent during the retrieval to a vessel of line-caught fish in areas where white sharks are naturally foraging (e.g. areas where snapper *Pagrus auratus* are abundant; Malcolm *et al*. 2001). All of these activities can add to the propensity for white sharks to approach a vessel. When combined with the species natural tendency to investigate surface objects, it is not surprising that vessel crew have reported the 'unsolicited' approaches of white sharks over many decades. Thus it will never be a trivial task to disentangle the overall potential impacts on shark behaviour as a result of shark cage diving alone from overall encounters with human activity across the movement range of the species.

5 Recommendations for white shark cage dive management in New Zealand

Experience in other jurisdictions emphasizes the importance of regulating shark cage diving industries in terms of both minimising the potential for impacts on sharks and the local environment, minimising conflict with and risks to other water users while ensuring economic viability and industry harmony. Important considerations include ensuring that managing agencies have the appropriate policy and legislative ability to create such regulatory frameworks. A common theme across all jurisdictions is to minimise impacts on white sharks in response to their listed conservation status.

Despite the lack of overall evidence to support that sharks exposed to cage diving pose any more or less threat to other water users than sharks not exposed to such activity, community concerns regarding cage diving activities remain an important issue for management and industry to consider as part of their social licence to operate.

Key elements for successfully managing white shark cage dive industries and minimising conflict between user groups include:

- a clearly articulated management plan and mandatory protocols for industry operation,
- limiting the number of licences to operate,
- restricting areas at which such operations can take place,
- mandatory and effective reporting of industry activities via a logbook system,
- establishing mandatory protocols that minimise impacts on sharks that may be detrimental to their well-being,
- establishing mandatory protocols that minimise the risk of conditioned behaviours arising in sharks exposed to industry operations,
- reducing overall impact on the local environment and other species at sites where cage diving occurs.

The latter three components are largely achieved by the same actions. Specifically, limiting the amount of chum/berley used, limiting the number of tethered (throw) baits consumed by sharks and establishing protocols that minimise injury to sharks via contact with cages and the diving vessel. Limiting the amount of chum/berley used specifically reduces the provisioning finfish in the area.

These components are largely covered by the existing DOC Code of Practice although specific limits on the amount of chum/berley used might be further considered.

Additional consideration should be given to limiting the number of days when cage dive operations can take place during a season at Stewart Island. Although sharks are only seasonally present in the Stewart Island area, research by Francis *et al*. (2015) indicates a near continuous presence of some individual sharks over multiple months during their period of occurence. Despite evidence that conditioned behaviours are unlikely given the extent of rewards received by sharks under the current DOC Code of Conduct (and in light of research pertaining to this topic elsewhere) such impacts cannot be unequivocally ruled out. Introducing regular days of non-operator activity as applied in South Australia may further reduce the risk of impacts to sharks in the area.

Introducing electronic logbooks has provided a cost and time efficient system of recording data from the industry in South Australia where a small number of operators are also licensed. Consideration should be given to adopting a similar system in New Zealand.

6 Recommendations for research

Recent research at cage dive sites in New Zealand and specifically at Stewart Island has focussed on local and regional patterns of movement and habitat use, using a combination of acoustic and satellite tags (Duffy *et al*. 2012, Francis *et al*. 2015). Initial work has also commenced on using photographic identification of sharks to determine the attendance patterns and numbers of animals using the cage dive site.

Research on movement patterns, habitat use and numbers of sharks utilising both the area around cage diving site and the surrounding region are key components for understanding the status of white shark populations in the area and their interplay with cage diving operations.

Additional areas of research are suggested that would define:

1. Localised movement patterns and habitat use

Further investigate the localised movement patterns of sharks in the Stewart Island region to determine patterns of local residency, abundance and movement pathways. This could be achieved by maintaining an acoustic tagging program matched with the deployment of acoustic receivers.

2. Local shark numbers and population size

Monitor the numbers of sharks utilising cage dive sites and investigate if these numbers vary over time. Photographic identification is a useful component here as used in other jurisdictions. However, additional genetic-based tools for estimating population size and determining the return of individuals to such sites are now becoming more cost effective. Genetic sampling via biopsy is recommended to commence such studies. Such samples may be archived initially in lieu of analyses.

3. Commercial fishing industry sightings register

Commercial fishers provide additional platforms to collect sightings data that can be useful for interpreting overall patterns of shark distribution. A register for white shark sightings in the region would be a useful way to harness such information particularly if matched with fishing effort records to standardise the sightings data.

7 References

Aguilar, M. T., Morales, O. S., Padilla, M. H. and Camarena, A. B. (2015). Code of conduct for great white shark cage diving in the Guadalupe Island Biosphere Reserve. Secretaria de Medio Ambiente y Recursos Naturales and Comision Nacional de Areas Naturales Protegidas. Miguel Hidalgo, D.F. Mexico City. 57 pp

Ainley, D. G., Henderson, R. P., Huber, H. R., Boekelheide, R. J., Allen, S. G. and McElroy, T. L. (1985). Dynamic of white shark/pinniped interactions in the Gulf of the Farallones. Memoirs of the Southern California Academy of Sciences 9: 109 – 122.

Bonfil, R., Meyer, M., Scholl, M.C., Johnson, R., O'Brien, S., Oosthuizen, H., Swanson, S., Kotze, D. and Paterson, M. (2005). Transoceanic migration, spatial dynamics, and population linkages of white sharks. Science 310: 100 – 103

Boustany, A.M., Davis, S.F., Pyle, P., Anderson, S.D., Le Boeuf, B.J. and Block, B.A. (2002). Expanded niche for white sharks. Nature 415: 35–36.

Bradford, R. and Robbins, R. (2013). A rapid assessment technique to assist management of the white shark (*Carcharodon carcharias*) cage dive industry, South Australia. Open Fisheries Science Journal 6: 13 - 18.

Bruce, B.D., Stevens, J.D. and Bradford, R.W. (2005). Site fidelity, residence times and home range patterns of white sharks around pinniped colonies. Final Report to the Australian Government Department of the Environment and Heritage. CSIRO Marine and Atmospheric Research, Hobart.

Bruce, B.D., Stevens, J.D. and Malcolm, H. (2006). Movements and swimming behaviour of white sharks (*Carcharodon carcharias*) in Australian waters. Marine Biology 150: 161 – 172

Bruce, B.D., and Bradford, R.W. (2013). The effects of shark cage-diving operations on the behaviour and movements of white sharks, *Carcharodon carcharias*, at the Neptune Islands, South Australia. Marine Biology 160: 889 - 907.

Brunnschweiler, J.M., Abrantes, K.G. and Barnett, A., (2014). Long-term changes in species composition and relative abundances of sharks at a provisioning site. PLoS ONE e94118. http://dx.doi.org/10.1371/journal.pone.0086682.

Burgin, S. and Hardiman, N. (2015). Effects of non-consumptive wildlife-oriented tourism on marine species and prospects for their sustainable management. Journal of Environmental Management 151: 210 - 220

Chapple, T.C., Jorgensen, S.J., Anderson, S.D., Kanive, P.E., Klimley, A.P., et al. (2011). A first estimate of white shark, Carcharodon carcharias, abundance off Central California. Biology Letters 7: 581–583.

Clua, E., Buray, N., Legendre, P., Mourier, J. and Planes, S. (2011). Business partner or simple catch? The economic value of the sicklefin lemon shark in French Polynesia. Marine and Freshwater Research 62: 764 - 770.

DENR (2011). Commercial tour operator licensing and permitting. Policy 2011. DENR 70/07/0243. Department of Environment and Natural Resources, Adelaide.

DENR (2012). Great white shark tourism (Neptune Islands Conservation Park) Policy 2012. Department of Environment and Natural Resources, Adelaide.

DEWNR (2015). South Australian white shark tourism policy – draft. Department of Environment, Water and Natural Resources. Adelaide, South Australia. 16 pp

Dicken, M.L. and Hosking, S.G. (2009). Socio-economic aspects of the tiger shark diving industry within the Aliwal Shoal Marine protected area, South Africa. African Journal of Marine Science 31: 227 - 232.

Domeier, M.L. and Nasby-Lucas, N. (2013). Two year migration of adult female white sharks (*Carcharodon carcharias*) reveals widely separated nursery areas and conservation concerns. Animal Biotelemetry 2013, 1:2

Duffy, C. Francis, M.P., Manning, M.J. and Bonfil, R. (2012). Regional population connectivity, oceanic habitat, and return migration revealed by satellite tagging of white sharks, *Carcharodon carcharias*, at New Zealand aggregation sites. *In* Global Perspectives on the Biology and Life History of the White Shark. Edited by Domeier ML. Boca Raton: CRC Press; 2012:301–318.

Francis, M.P., Duffy, C. and Lyon, W. (2015). Spatial and temporal habitat use by white sharks (*Carcharodon carcharias*) at an aggregation site in southern New Zealand. Marine and Freshwater Research http://dx.doi.org/10.1071/MF14186

Fitzpatrick, R., Abrantes, K.G., Seymour, L. and Barnett, A. (2011). Variation in depth of whitetip reef sharks: does provisioning ecotourism change their behaviour? Coral Reefs 30: 569 - 577.

Gallagher, A.J. and Hammerschlag, N. (2011). Global shark currency: the distribution and frequency, and socio-economics of shark ecotourism. Current Issues in Tourism. 14, 797 - 812.

Gaspar, C., Chateau, O., Galzin, R., 2008. Feeding sites frequentation by the pink whipray, *Himantura fai*, in Moorea (French Polynesia) as determined by acoustic telemetry. Cybium 32: 153 - 164.

GN-R723 (2008). Policy on white shark cage diving. Government Notice R723; Government Gazette 31210. Department of Environmental Affairs and Tourism, South Africa.

GN-R724 (2008). Regulation for the management of white shark cage diving. Government Notice R724; Government Gazette 31211. Department of Environmental Affairs and Tourism, South Africa.

Hammerschlag, N., Gallagher, A.J., Wester, J., Luo, J. and Ault, J.S. (2012). Don't bite the hand that feeds: assessing ecological impacts of provisioning ecotourism on an apex marine predator. Functional Ecology 26: 567 - 576

Hara, M., Maharaj, I. and Pithers, L. (2003). Marine-based Tourism in Gansbaai: a Socioeconomic Study. Department of Environmental Affairs and Tourism, Cape Town.

Huveneers, C., Rogers, P., Beckmann, C., Semmens, J., Bruce, B. and Seront, L. (2013). The effects of cage-diving activities on the fine-scale swimming behaviour and space use of white sharks. Marine Biology. doi:10.1007/s00227-013-2277-6

Johnson, R. and Kock, A. (2006). White shark cage diving-cause for concern? In: Nel, D.C., Peshak, T. (Eds.), Finding a Balance: White Shark Conservation and Recreational Safety in the Inshore Waters of Cape Town, South Africa. WWF South Africa, Cape Town, pp. 40 - 59. WWF South African Report Series 2006/Marine/001.

Jorgensen, S.J., Reeb, C.A., Chapple, T.K., Anderson, S., Perle, C., Sommeran, S.R., Fritz-Cope, C., Brown, A.C., Klimley, A.P. and Block, B.A. (2009). Philopatry and migration of Pacific white sharks. Proceedings of the Royal Society B. doi:10.1098/rspb.2009.1155

Klimley, A.P. (1994). The predatory behaviour of the white shark. American Scientist 82:113 – 122.

Klimley, A.P., Le Boeuf, B.J., Cantara, K.M., Richert, J.E., Davis, S.F. and Van Sommeran, S. (2001). Radio-acoustic positioning as a tool for studying site-specific behaviour of the white shark and other large marine species. Marine Biology 138: 429 – 446.

Laroche, R.K., Kock, A.A., Dill, L.M. and Oosthuizen, W.H. (2007). Effects of provisioning ecotourism activity on the behaviour of white sharks, *Carcharodon carcharias*. Marine Ecology Progress Series 338: 199 – 209.

Malcolm, H., Bruce, B.D. and Stevens, J.D.S. (2001). A review of the biology and status of white sharks in Australian waters. Final report to Environment Australia, Marine Species Protection Program. CSIRO Hobart. 114 pp

Maritime New Zealand (2014). Safety guidelines for commercial shark cage diving. Maritime New Zealand. 22 pp

Martin, R.A., Hammerschlag, N., Collier, R.S. and Fallows, C. (2005). Predatory behaviour of white sharks (*Carcharodon carcharias*) at Seal Island, South Africa. Journal of the Marine Biological Association of the UK 85: 1121 – 1135

Nasby-Lucas, N., Dewar, H., Lam, C.H., Goldman, K.J. and Domeier, M.L. (2009). White shark offshore habitat: A behavioral and environmental characterization of the eastern Pacific Shared Offshore Foraging Area. PLoS ONE 4(12): e8163. doi:10.1371/journal.pone.0008163

Newsome, D., Lewis, A., Moncrieff, D., 2004. Impacts and risks associated with developing, but unsupervised, stingray tourism at Hamelin Bay, Western Australia. International Journal of Tourism Research. 6: 305 - 323.

NOAA (2014). Draft programmatic environmental assessment of potential white shark research and education projects within the Gulf of the Farallones and Monterey Bay National Marine Sanctuaries. Office of the National Marine Sanctuaries National Ocean Service. National Oceanic Atmospheric Administration. 117 pp.

Orams, M.B. (2002). Feeding wildlife as a tourism attraction: a review of issues and impacts. Tourism Management 23: 281 - 293

Rogers, P.J, Huveneers, C. and Beckmann, C.L. (2014). Monitoring residency of white sharks, *Carcharodon carcharias* in relation to the cage-diving industry in the Neptune Islands Group Marine Park. Report to the Department of Environment, Water and Natural Resources. SARDI Aquatic Sciences. SARDI Publication No. F2014/000801-1 SARDI Research Report Series No. 818. 69pp.

Semmens, J.M., Payne, N.L., Huveneers, C., Sims, D.W. and Bruce, B.D. (2013). Feeding requirements of white sharks may be higher than originally thought. Scientific Reports – Nature: DOI: 10.1038/srep01471

Smith, K., Scarr, M. and Scarpaci, C. (2010). Grey nurse shark (*Carcharias taurus*) diving tourism: tourist compliance and shark behaviour at Fish Rock, Australia. Environmental Management 46, 699 – 710.

Smith, J. K. and Page, B. (2015). Decision points for White Shark Tourism Policy, DEWNR Technical note 2015/09, Government of South Australia, through the Department of Environment, Water and Natural Resources, Adelaide. 12 pp.

Strong, W.R. Jr, Bruce, B.D., Nelson, D.R. and Murphy, R.C. (1996). Population dynamics of white sharks in Spencer Gulf, South Australia. In: Klimley AP, Ainley DG (eds) Great White Sharks: the biology of *Carcharodon carcharias*. Academic Press, San Diego, pp 401 – 414.

Topelko, K.N., Dearden, P., 2005. The shark watching industry and its potential contribution to shark conservation. Jornal of Ecotourism 4: 108 - 128.

Towner, A.V., Wcisel, M.A., Reisinger, R.R., Edwards, D., and Jewell, O.J.D. (2013). Gauging the Threat: The first population estimate for white sharks in South Africa using photo identification and automated software. PLoS ONE 8(6): e66035. doi:10.1371/journal.pone.0066035

Weng, K.C, Boustany, A.M., Pyle, P., Anderson, S.D., Brown, A. and Block, B.A. (2007). Migration and habitat of white sharks (*Carcharodon carcharias*) in the eastern Pacific Ocean. Marine Biology 152: 877 – 894.

Appendix 1: Summary of white shark cage dive industry management by jurisdiction.

Management action	Mexico	South Africa	California	Australia	New Zealand
Specific cage-dive management plan/policy? (latest version)	# Yes (2015)* *Aspects under review	# Yes (2008)	# Yes (2009)* *Under review	# Yes (2012)* *Under review	Yes (2014)* *Under review
Code of Conduct	# Published - 2015	# Available –details safety requirements and client service/briefing		# Industry Code of Conduct - 2009	# Published 2013
Managing agency	# Secretariat of Environment and Natural Resources (SEMARNAT) + # National Commission of Natural Protected Areas (CONAP)	# Department of Environmental Affairs	# Office of National Marine Sanctuaries, National Oceanic and Atmospheric Administration	# Department of Environment, Water and Natural Resources (DEWNR) # Primary Industries and Regions South Australia (PIRSA)	# Department of Conservation (DOC) # Maritime New Zealand (Safety including cage construction)
Management objectives	# Ensure sustainability and conservation of Guadalupe Island Biosphere Reserve # Prevent any possible negative and harmful impact or disturbance on the natural behaviour and habitat of white shark # Guarantee the species conservation and achieve its sustainable use from the environmental, social and economic points of view	# Provide for control over diving to view white sharks or the boat base viewing of white sharks so that these activities may take place in a manner that does not threaten the safety of divers or the well-being of the shark. # Provide control over the number of white shark cage diving operations in order to manage any adverse impact on white shark behaviour and to protect white sharks. # Promote the economic	# Further research and monitoring related to Sanctuary resources and qualities; further the educational value of the Gulf of the Farallones and Monterey Bay National Marine Sanctuaries Sanctuary. # Protect and conserve the white shark population # Prevent disturbances and alterations to white shark natural behaviours	# Enable the sustainable development of the South Australian White Shark tourism industry within Neptune Islands Conservation Park by defining the circumstances under which commercial activities may take place and by fostering competition # Develop an understanding of the impacts of tourism activities and prevent any risk to white sharks which could harm sharks or compromise recovery of	# Cage dive operators must conduct their activities in a manner which does not harm white sharks

		growth of the white shark industry and the sustainable non-consumptive use of white sharks, particularly for ecotourism"		the species; # Avoid and minimise impacts on reserve values; and # Improve industry certainty and reduce red tape.	
Government fees?	# Yes	# Yes		# Yes	
Permit renewal	# Permit to operate – every two years (CONAP) # Annual permit to interact with protected species (SEMARNAT)	# Annually renewable for five years		# Permit to operate (DEWNR) – every five years # Permit to berley (PIRSA) annually	
Number of permits/operators	# No limit specified – currently six	# No limit specified but the allocation of permits will be "..informed by a precautionary management plan". Up to 14 have operated	# No limit specified; currently 2-4 operators on a seasonal basis	# Up to maximum of three – currently three	# No limit specified – currently 2
Number of vessels	# No limit – currently six;	# Each operator may register two vessels, but only one can be used at any given time	# No limit specified	# One operating vessel per permit at any time	
Limits on chum/berley	# Chum/berley not permitted (since 2013)	# Fish products only; Maximum of 25 kg per day	# Not permitted	# Teleost fish products only – no current limit	# No limit; Fish products only berley must be finely minced so as not to offer a food source to sharks
Limits on bait	# Teleost fish products only; no limit on baits lost to sharks	# Teleost fish products only, included within the 25 kg per day limit as above	# Not permitted	# Teleost fish products only – no current limit tly	#Fish products only #Allowance of one bait lost per day - in the event that a shark takes or consumes a bait, no further baits may be used on that day #Only one bait to be used at a time

Bait handling	# Attached to vessel by rope (min length = 12 m) # Baits must be not be presented or retrieved immediately in front of cages nor allowed to touch cages # Immediately remove bait from water if shark approaches within 2 m of vessel # Bait handler to drop line if shark takes bait	# Minimum requirement for at least two crew to have min 180 hrs of experience # Baits tied down with natural fibre rope # Sharks must not be encouraged to ingest bait # Bait handler to drop line if shark takes bait # No baits attached to cages # Bait line shall not touch cage at any time or be retrieved over cage	# Not applicable	# Take care at all times not to cause injury or stress to sharks	# Bait ropes to be made of natural biodegradable fibre and securely attached to vessel # Baits not to be pulled or allowed to drift into cage # Baits must not be deployed from cages # Baits to be not be recovered in a manner that is likely to cause shark to collide with cage
Use of decoys	# Not permitted	# Permitted with prior permission	# Static decoys (no towing) permitted # Constructed of soft material only (no Styrofoam)	# Not permitted	#Not permitted
Imposed operator free days?	# No	#Seal Island, Mossel Bay and Quoin Point areas closed from 1 Dec to 20 Jan	#No	# Yes, activity days restricted to 10 days in every fortnight	# No
Spatial restrictions?	# One site of approximately 607 ha on the NE side of Guadalupe Island # Max of three anchorage manoeuvres per day	# Seal Island, False Bay; Dyer Island, Gansbaai; Quoin Rock, Quoin Point; Seal Island, Mossel Bay; Algoa Bay, Port Elizabeth; specific sites located within each area.	# Limited to Farallon Islands only	# Limited to the Neptune Islands only	# Limited to within 300 m of Edwards Island (near Stewart Island)
Number of cages/divers	# No limit; max of four divers per cage	# No limit	# No limit	# No limit	# No limit
Diving outside of cage	# Not permitted	# No permitted under normal circumstances but separate authority to do			# Not permitted

		so may be granted			
Touching sharks	# Not permitted	# Not permitted			# Not permitted
Rec/sports fishing	# Permitted but not during cage-dive operations			# Not permitted	# Not permitted
Cage design	# Design to be checked by Management of the Biosphere Reserve Guadalupe Island (DRBIG) # Annual checks by engineer # No sharp edges; smooth welds # Max distance between bars – 35 cm # Emergency floatation device fitted # Top access door – closed during operations # Attached to vessel with floating rope	# Detailed plans must be submitted to Department including a certificate of endorsement from a structural engineer # Annual checks by engineer Must have freeboard of 300 mm # No sharp edges # Top access door # Attached to vessel by min of two 14 mm dia ropes and float not more than 30 cm from vessel			# Cage design approved by registered engineer # No sharp edges; smooth welds # Viewing window height of no more than 400 mm # Top access door, closed when while in water # Attached to vessel by an arm, ramp or chain/wire ropes; if tethers are used there should be four as short as possible
Distance separation requirements	# Minimum distance = 450 m			# Minimum distance = 200 m	# Minimum distance of 200 m to another vessel # Minimum distance of 1000 m from swimmers or other diving activities
Record keeping	# Mandatory (paper-based) logbook "Activity report" submitted at the end of each trip (to DRBIG)	# Mandatory (paper-based) daily log, submitted monthly to Department	# Mandatory (paper-based) trip logbook submitted at end of season	# Mandatory electronic logbooks	# Mandatory (paper-based) trip log submitted to DOC on a monthly basis
Education	# Information (from DRBIG) about the Biosphere Reserve, Guadalupe Island to be	# All operators to provide adequate interpretation/ education services as prescribed in addition to	# Vessels must provide a trained naturalist		

	made available to clients	a registered tour guide (South African Tourism Act)			

Note: Blank field indicate information not specified.