Longline Weak Hook Testing in the Mouths of Pelagic Delphinids: Soft and Hard Tissue Hook Deformation Tests

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Final Report of activities on grant # 2592

from New England Aquarium Corporation

to University of North Carolina Wilmington

Summary

A series of five commercially available and consistently fished longline hooks were tested to measure the forces required to pull these hooks through the soft and hard tissues in the mouths of small toothed whales and to document the resulting tissue injuries. The hooks included the M-16, M-18, K-16, K-18 and J-9 and were tested in new “out of the box” condition. The M-16, M-18 and J-9 hooks were polished steel while the K-16 and K-18 were carbon forged hooks.

Tests were conducted on three species of pelagic delphinid cetaceans that have been documented to interact with commercial longline fisheries in both the Atlantic and Pacific - short-finned pilot whales (*Globicephala macrorhynchus*), Risso’s dolphins (*Grampus griseus*) and false killer whales (*Pseudorca crassidens*). All specimens were collected from strandings on the Outer Banks of North Carolina, frozen for high-quality archival storage and then thawed completely in water just prior to mechanical tests. Intact heads were secured to a fixed stanchion and hooks were serially placed in the mouth at multiple positions along the dorsal lip and lower jaw. These tests were conducted specifically to determine the forces required to pull these hooks through soft lip tissues and to determine if they could fracture the lower jaw bone of these odontocetes. Forces were collected with an in-line force gauge and downloaded to a computer for analysis.

The polished steel (M and J), and carbon forged (K) hooks types behaved in measurably different ways during these tests. M- 16, M-18 and J-9 hooks, embedded in soft tissues, all straightened under maximum forces that ranged from 50 – 225 kg, depending upon the hook gauge. These hooks straightened enough to expose the sharpened tip barb, which sliced through the lip tissue, releasing the hook, usually intact. The resulting wounds were typically linear slices, which ran from the site of hook penetration on the deep lip to the lip’s lateral margin. The injury on the lateral lip was usually a vertically oriented linear or inverted v-shape cut, similar to healed lesions observed on the lips of stranded specimens. Experimentally induced, shallow lacerations wounds of a similar nature have been documented to heal completely in the blubber and skin of bottlenose dolphins (*Tursiops truncatus*) in as little as seven days (Bruce-Allen and Geraci, 1985).

K-16 and K-19 hooks embedded in soft tissues behaved very differently. Although these hooks did bend during mechanical tests, they did not open to expose the sharp tip barb, and thus, did not slice through lip tissues. Instead, the hook either broke or tore through the lip. The resulting wounds from K hooks were large, irregular, jagged, tissue lacerations and tears. In most cases, there was measurable soft-tissue loss, and the resulting wounds were more variable than those resulting from the M and J hooks. In addition, these hooks would generally break at relatively high loads (70-250 kg) at a very consistent position along their length - just behind the barb. This type of failure often left shards of the hook tip in the soft tissue of the gum.

The different behaviors of these two hook types – the M and J type polished steel versus the K type forged iron – were consistent across all species tested. Thus, their mechanical behavior appeared to depend upon the material from which the hook was manufactured. The steel hooks bent smoothly and

created a clean slice to exit the lip, while the carbon hooks did not exit until the lip tissue was torn and/or the hook broke. The soft tissue lips of the pelagic delphinids tested here were capable of resisting sizable forces of up to 250 kg before failing.

Additional mechanical tests were conducted to determine if the hooks used in the longline fishery could fracture the mandible (lower jaw) of these pelagic odontocetes. Only the M-18 and K-18 hooks were large enough to be placed into the mouth around the lower jaw (smaller hooks could be placed onto the dorsal surface of the mandible, but did not have sufficiently large gapes to fit around the jaw bone). Both of these hook types fractured the jaws in short-finned pilot whales and Risso's dolphins. These results add to the evidence that longline hooks can cause serious injury to the jaw of these species.

Introduction

Multiple species of odontocete cetaceans are known to depredate upon, and become seriously injured and killed within, pelagic longline fisheries (reviewed by Hamer *et al.* 2012). We proposed to conduct a series of experiments in support of efforts by two NOAA Take Reduction Teams to find solutions to the entanglement of short-finned pilot whales (*Globicephala macrorhynchus*) and false killer whales (*Pseudorca crassidens*) in longline fisheries. This work focused on measures that would reduce the serious injury of large odontocetes after they become hooked by pelagic longline gear, by testing how various hooks, including "weak hooks", behave within the soft and hard tissues of the odontocete mouth.

Weak hooks are designed to exploit differences in size (and, thus, hypothesized strength) of target (*e.g.* tuna, swordfish) and non-target (*e.g.* large odontocetes) species in pelagic longline fisheries (e.g. Bayse and Kerstetter 2010). Recent studies suggest that the use of weak hooks has little effect on the catch of target fish species and does result in the retrieval of more straightened hooks from the fishery (Bayse and Kerstetter 2010, Bigelow *et al*. 2012, Kerstetter 2012). These are promising results, but there is little empirical information on the interaction between odontocetes and weak hooks themselves because of low catch rates of these species in commercial fisheries (Bigelow *et al.* 2012, Hamer *et al*. 2012). Understanding how fishing gear interacts with cetacean soft tissues has yielded important insights that can be used to identify, and, thus, potentially mitigate the impacts of such entanglements (*e.g*. Winn *et al*. 2008, Barco *et al.* 2010).

Project Goal and Objective

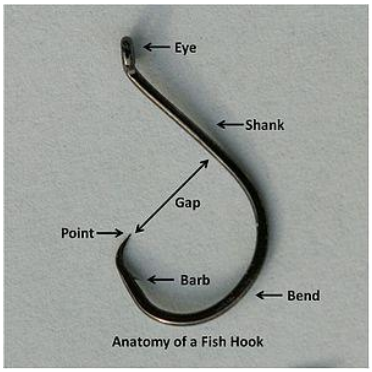
The specific goal of this project was to determine the force required to pull various commercially available hooks through the lips and jaws of short-finned pilot whales, false killer whales, and Risso's dolphins (*Grampus griseus*), all species that have been identified to be taken by longline fisheries (Waring *et al.* 2011, 2012). The objective was to provide biological guidance for identifying potential hook designs, including commercially available "weak hooks", which could minimize the potential for serious injury by understanding the hook bending capacity of the hard and soft tissues of the mouths of these odontocete species.

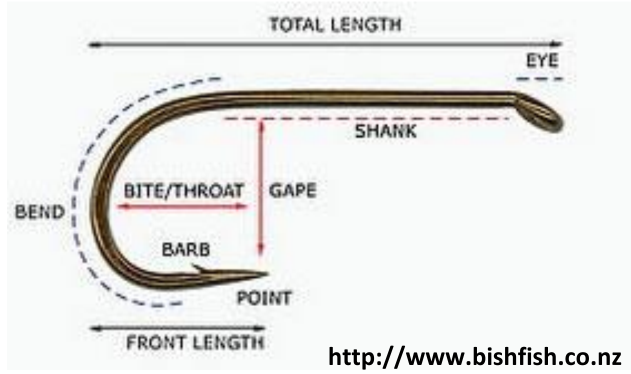
Materials and Testing

A specialized testing stanchion was constructed to firmly secure and support entire heads of pelagic odontocetes for hook and tissue deformation tests (see Figure 1). Heads were strapped onto the stanchion, which was secured to the floor with weights. The orientation of each head could be varied to provide multiple pulls of the hooks in both a dorsal-caudal and ventral-caudal direction. These force vectors were designed to mimic the pulling a pelagic cetacean would apply to a hook and gangion on main line of a commercial longline fishery. Force was applied with a 3 ton overhead crane that pulled at a rate of 4 cm/sec. Forces were transmitted to the hooks through a braided steel cable secured with small cable binders. Force was recorded with an MLP-1000 in-line load cell (Transducer Techniques, Temecula, CA) (see Figure 2) that collected strains at a sampling rate of 20Hz and directly downloaded to a computer. The force gauge was positioned in-line between the hook and the overhead crane.

Hooks that were tested included the Mustad 16/0 (#39988D), Mustad 18/0 (#39960D), Mustad 9/0 J (#7698B), Korean carbon 16 and Korean carbon 18 hooks. A complete suite of hook measurements is provided in Table 1. The choice of hooks was initially made in consulation with Dr. David Kertstetter at Nova Southeast Univeristy. The choice of hooks was subsequently discussed with members of the the Pelagic Longline Take Reduction Team (PLTRT) and team members suggested adding the Mustad J-9 hook. Multiples of each of these hooks were secured and tests were conducted to determine each hook's mechanical behavior in multiple species of cetaceans.

The species selected for hooking tests (Table 2) have all been taken in commercial longline fisheries. Short-finned pilot whales (*Globicephala macrorhynchus*) have been documented to be taken in longline fisheries off the Outer Banks of North Carolina (Waring 2012, Pelagic Longline Take Reduction Team website). Risso's dolphins (*Grampus griseus*) have been taken in pelagic longline fisheries off the northeast coast of the US (Waring 2012, Pelagic Longline Take Reduction Team website). The North Carolina Marine Mammal Stranding Network has worked collaboratively to maximize the data collected from all cetacean strandings and we requested carcasses to be collected specifically of the above species. In addition, a single false killer whale (*Pseudorca crassidens*) stranded on the Outer Banks of North Carolina and, due to the rarity on the east coast, was necropsied and extensively sampled. One of the many possible uses of tissues collected from that stranding event was to contribute to the hooking study being undertaken at UNCW and efforts were made to coordinate shipment of the frozen head back to UNCW for work up here. While false killer whales have not been documented to be taken in longline fisheries in the Atlantic, we include these data here to assist in conservation efforts of the Pelagic Longline Take Reduction Team.





Hook Type	Total Length(mm)	Gape(mm)	Bite (mm)	Gauge (mm)	Weight (g)
M-16	62	25	38	3.6	12
M-18	75	30	45	4.9	26
J-9	74	27	36	4.8	16
K-16	60	25	30	4.5	17
K-18	76	24	39	5.1	26

Table 1. Measurements of hooks investigated in this study.

Common Name	Species	Field #	Sex	TL cm	TM kg	Age Class
Short-finned pilot whale	*Globicephala macrorhynchus*	KLC 111	F	244	179	sub-adult
Short-finned pilot whale	*Globicephala macrorhynchus*	CAHA 093	M	269	334	sub-adult
Risso's Dolphin	*Grampus griseus*	KLC 136	F	254	163	adult
Risso's Dolphin	*Grampus griseus*	KLC 123	M	276.5	256.5	adult
False Killer Whale	*Pseudorca crassidens*	KLC 053	F	432	N/E	adult

Table 2. Odontocete cetacean specimens used in the study. All specimens were collected as fresh strandings in North Carolina, transported to UNCW and remained frozen at -20F until thawed for experimentation.

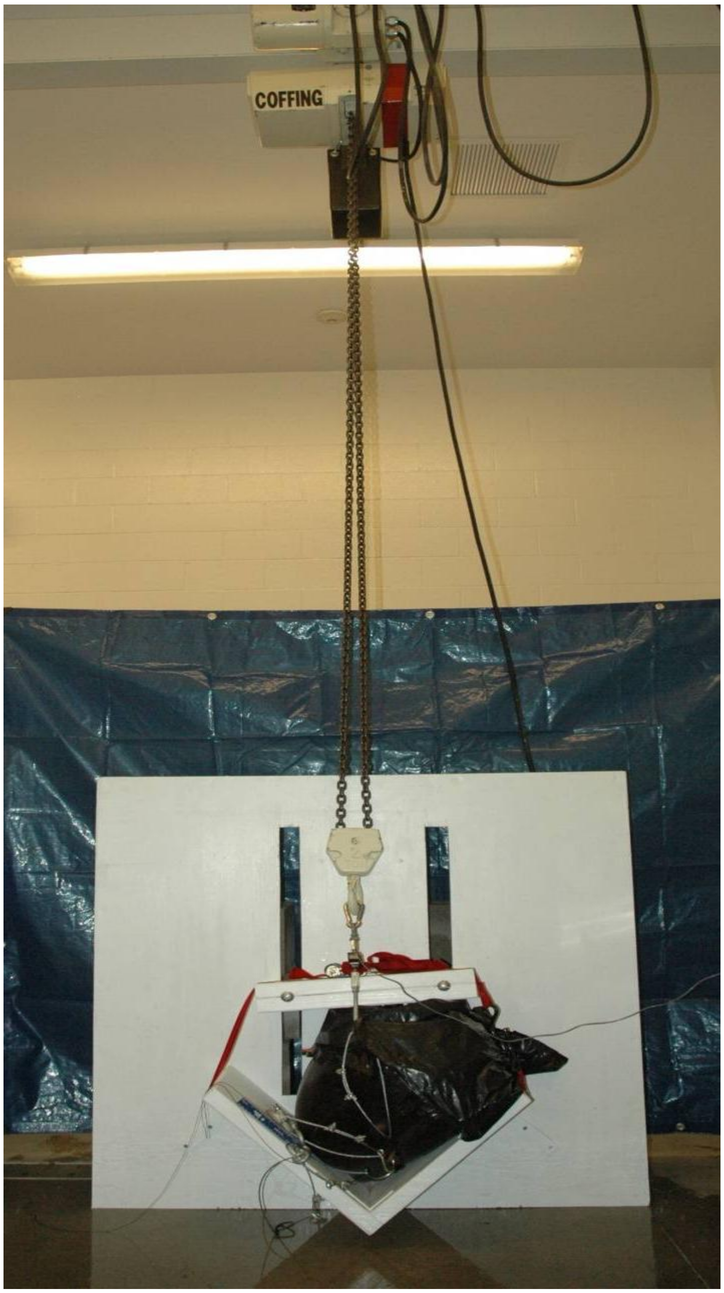


Figure 1. **Set up of testing apparatus with overhead crane supplying force, in-line force gauge (sample rate 20 Hz), and a short-finned pilot whale head secured in stanchion. There are four types of hooks that have been placed in the dorsal lip of the pilot whale for testing during this test run.**

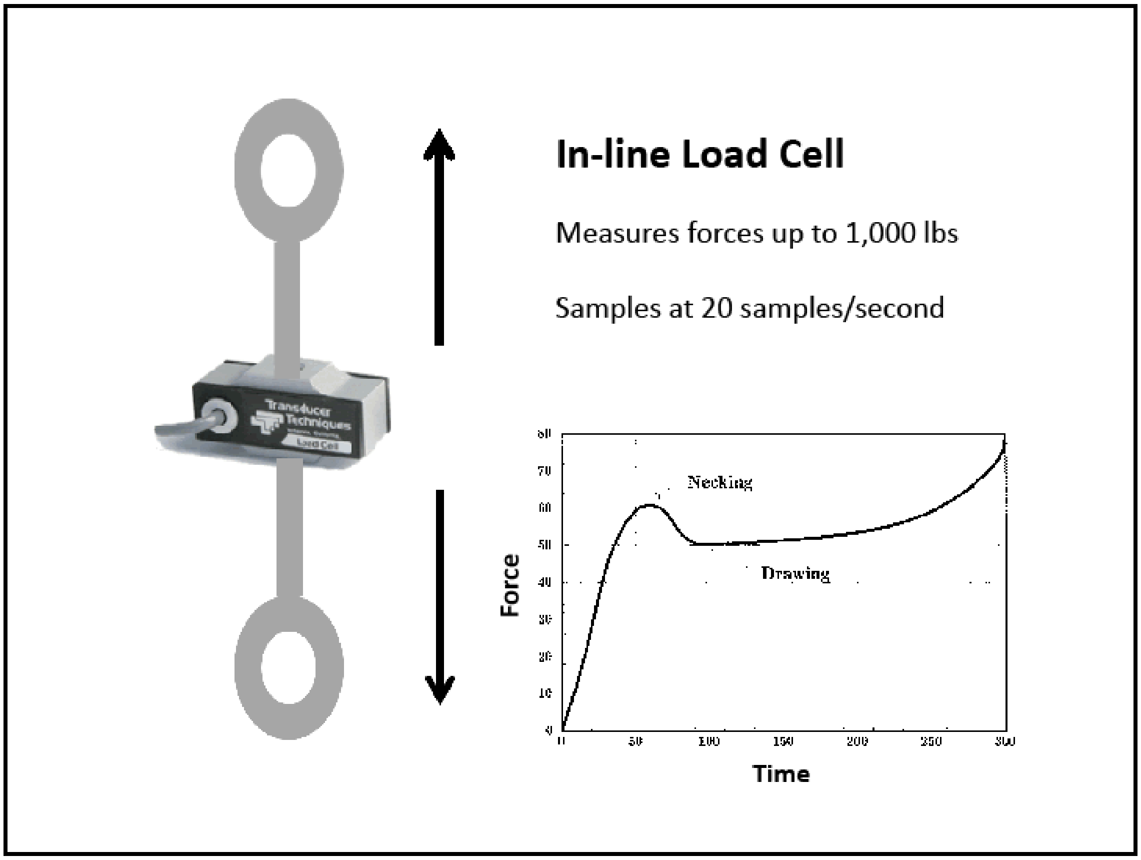


Figure 2. In-line straing gauge that transduced forces applied to bend or break hooks directly. Inset graph shows an example of a force over time plot presented below.

Results

All hooks used in the study were first calibrated to test the bending/breaking behavior under the same testing conditions as were used in the cetacean tissues tests. Hooks were pulled against a fixed platfom until the hook bent and released or fractured and released. The following Figures 3 - 7 describe the bending/breaking behavoir (reported in kg of in-line force) for each of the hook types.

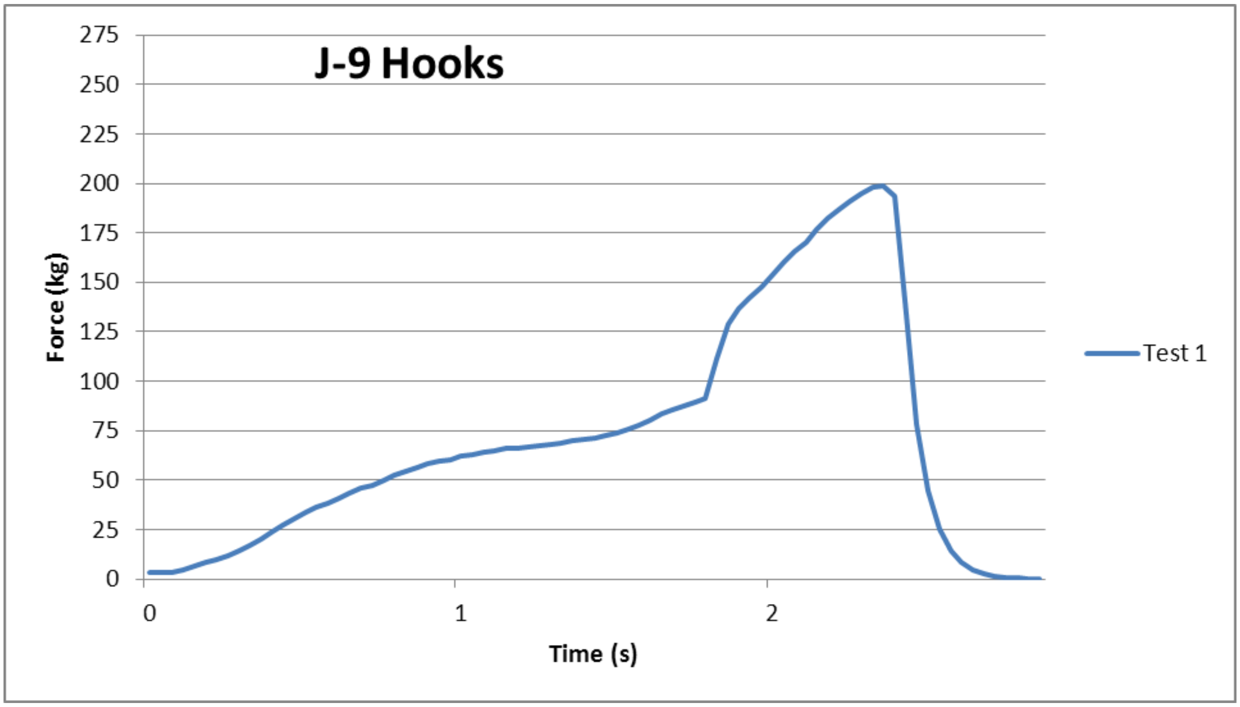


Figure 3. J-9 hook breaking test. Force builds until the hook straightens at approxmately 200 kg.

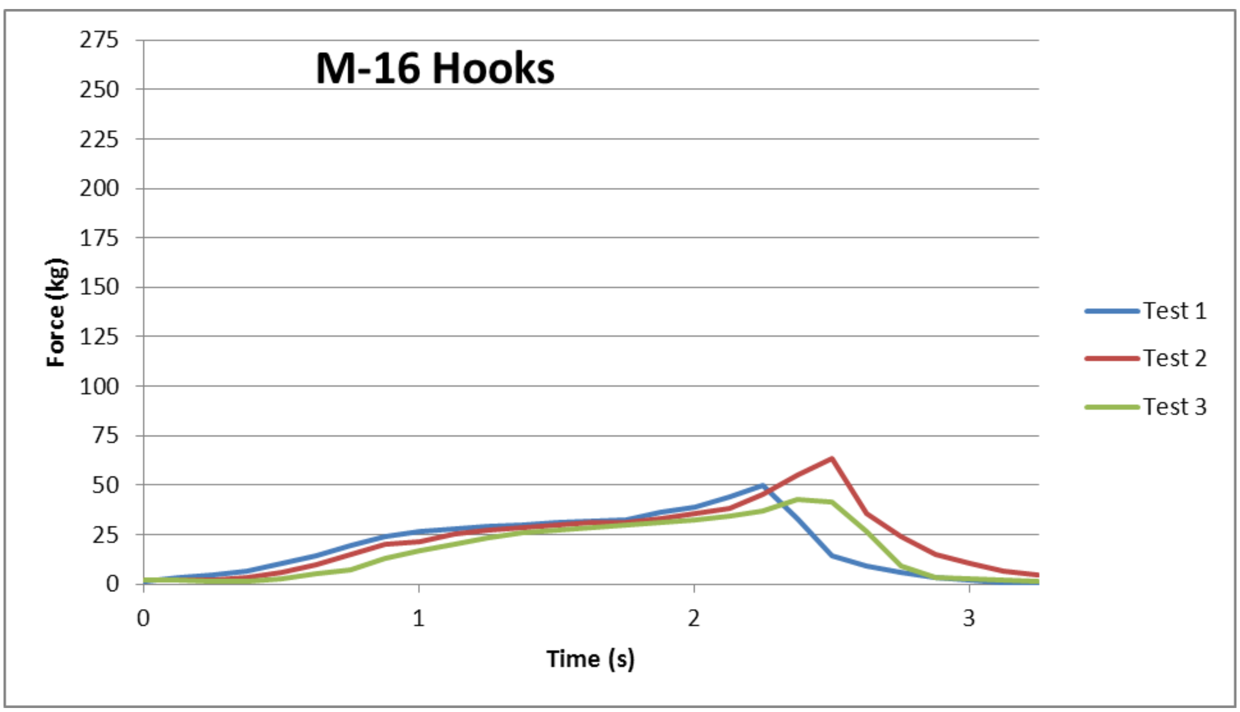


Figure 4. M-16 hook breaking tests. Force builds until hooks straighten between 40-60 kg.

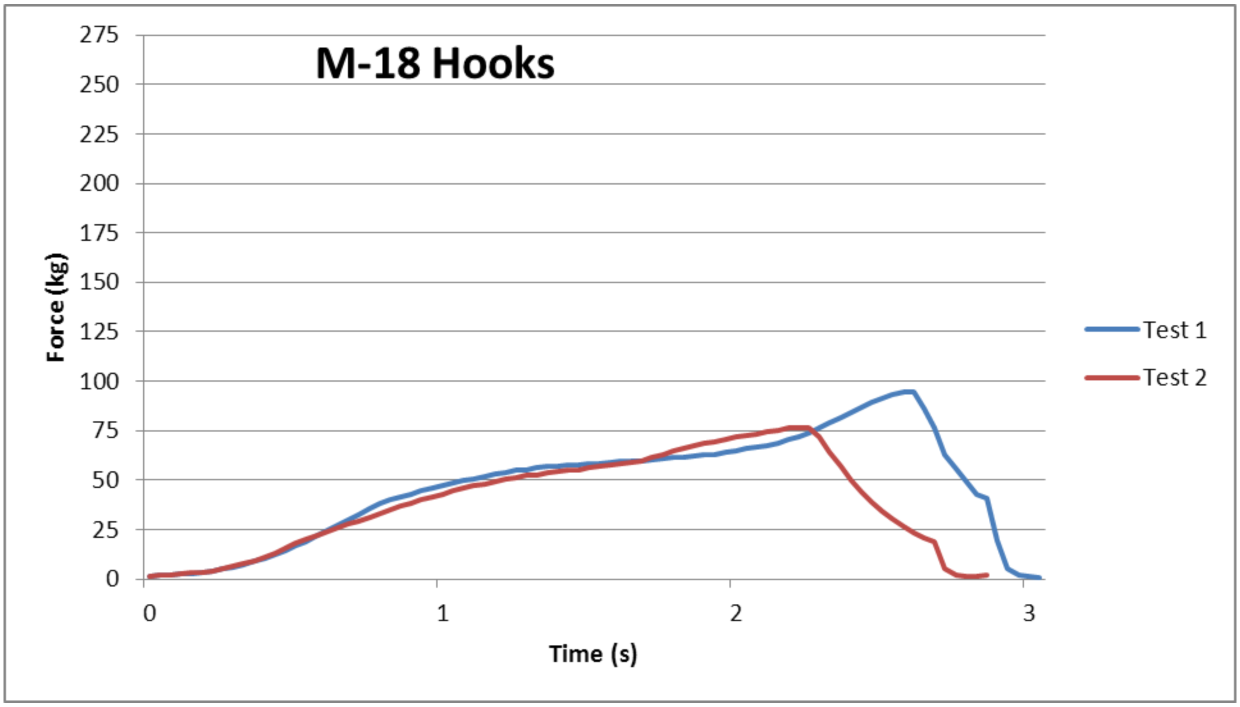


Figure 5. M-18 hook breaking tests. Force builds until hooks straighten between 75-90 kg.

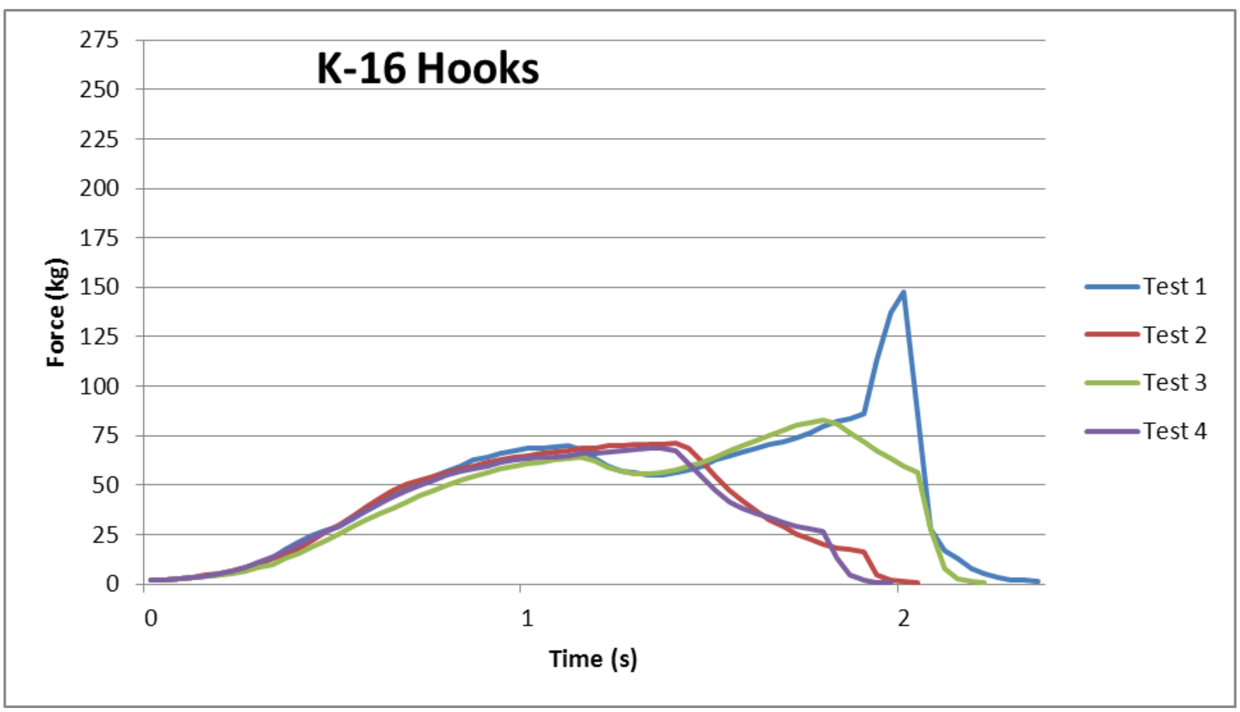


Figure 6. K-16 hook breaking tests. Force builds until hooks bend at approximately 75 kg or break at approximately 150 kg.

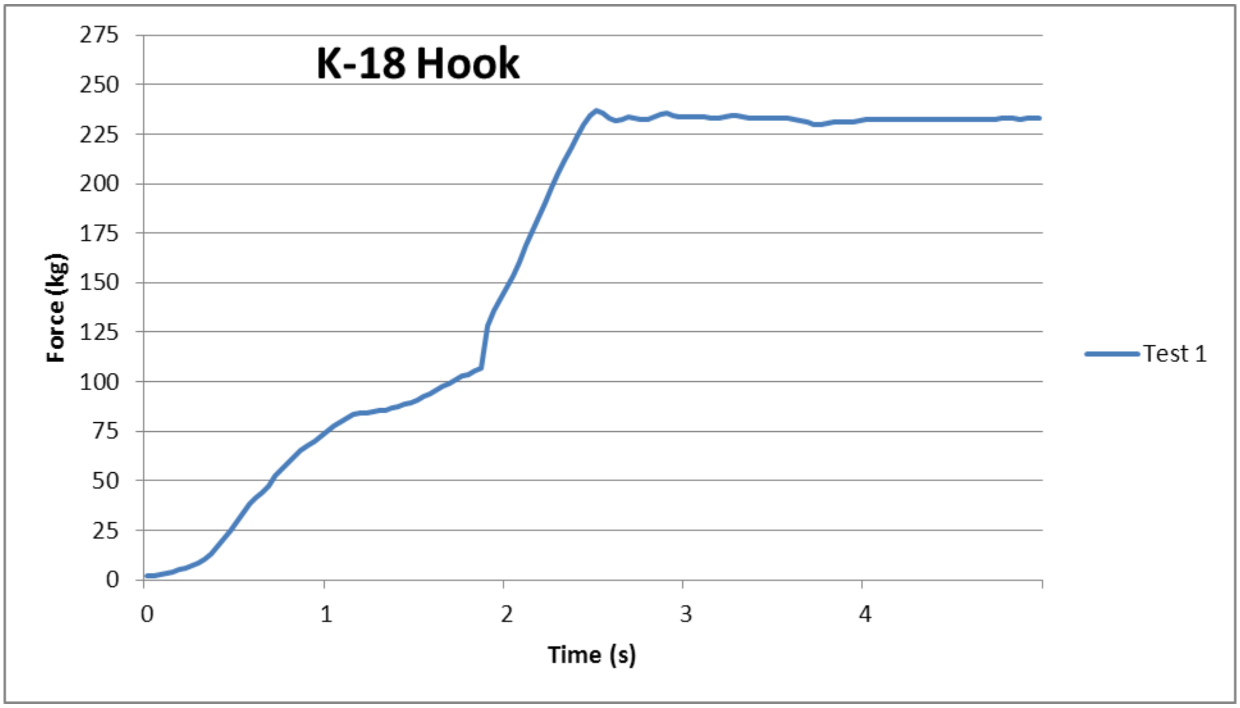


Figure 7. K-18 hook breaking test. Force builds until the hook lifts testing apparatus at approximately 225 kg.

Each hook type was tested on each specimen, and in some cases, mulitple times in a single individual. Figures 8 - 12 describe the pooled results for each hook type. Each line is identified by the specimen's field number (see Table 2) and for the type of test conducted. For hooks placed in dorsal lip tissues, "c" denotes a primarily caudal pull and "d" denotes a primarily dorsal pull. The "m" denotes a hook placed on the mandible (i.e. lower jaw) that underwent a primarily ventral pull. These force vectors were controlled by the posture of the head within, and the position of the crane above, the testing apparatus (see Figure 1).

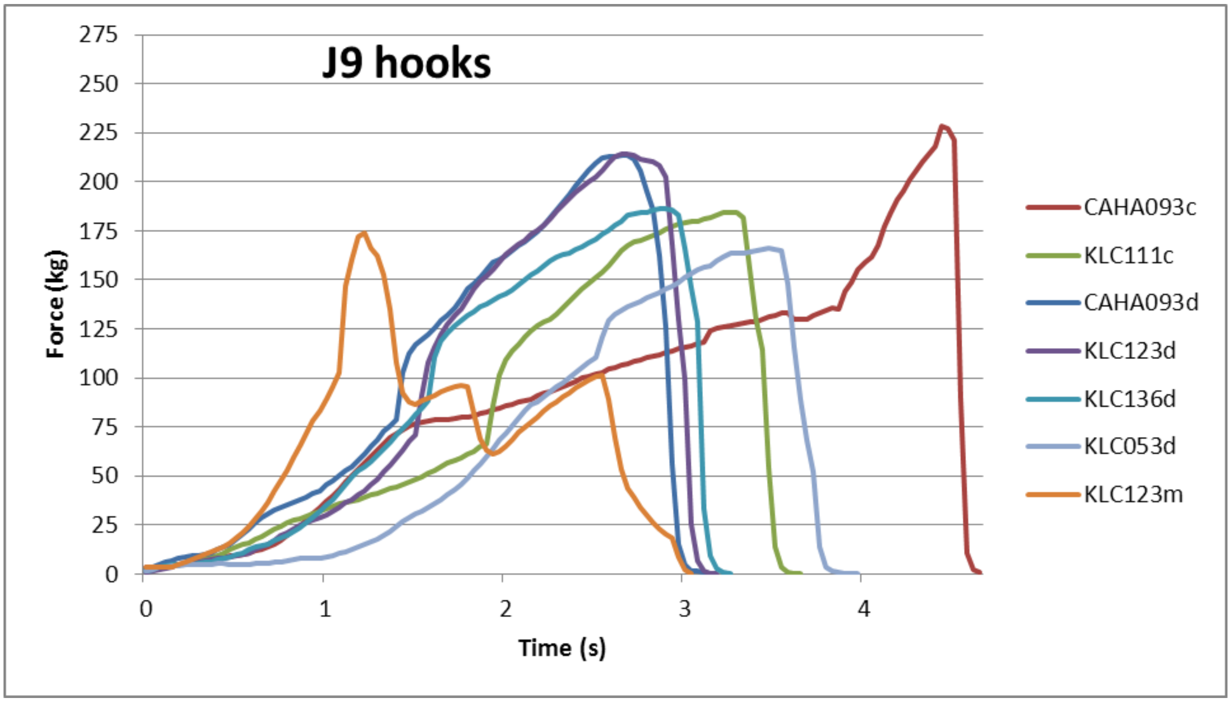


Figure 8. J-9 hooks in all specimens tested. All J-9 hooks straightened at maximal loads between 166-228 kg. In one test (KLC 123m) the hook was placed on the dorsal surface of the mandible just behind the tooth row, but the J-9 did not have a large enough gape and bite to hook around the jaw. During this test, the hook partially straightened, pulled across the surface of the mandible, and released.

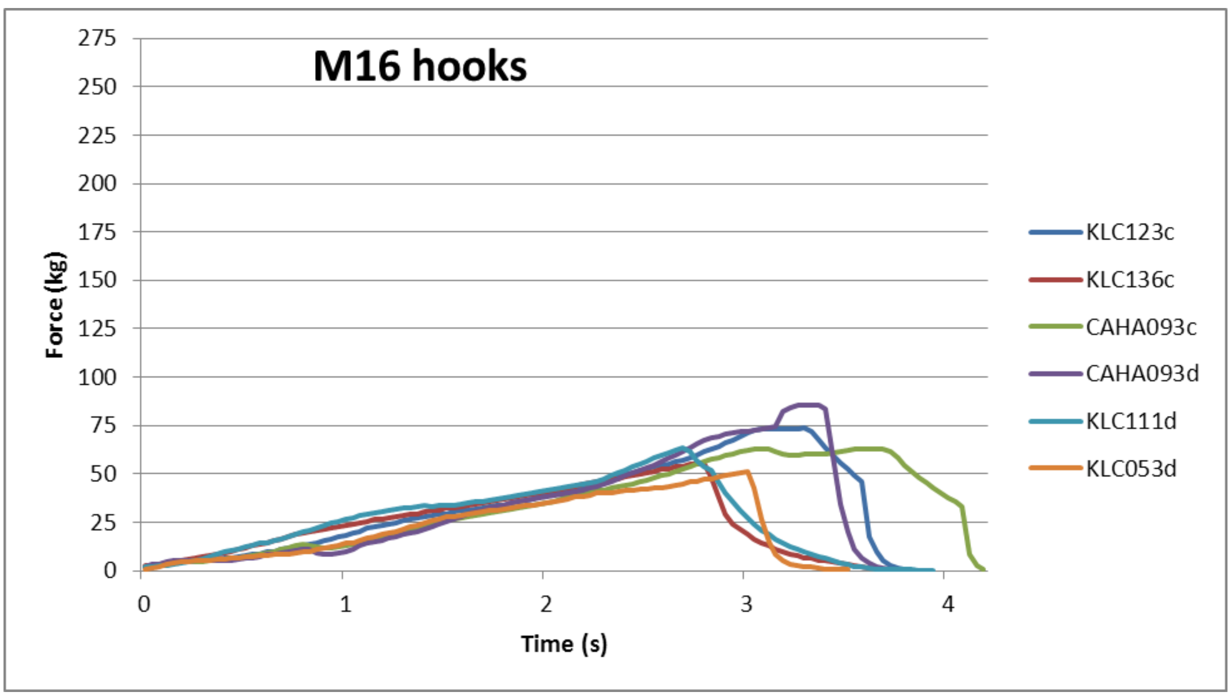


Figure 9. M-16 hooks in all specimens tested. All M-16 hooks straightened at maximal loads beween 51-85 kg.

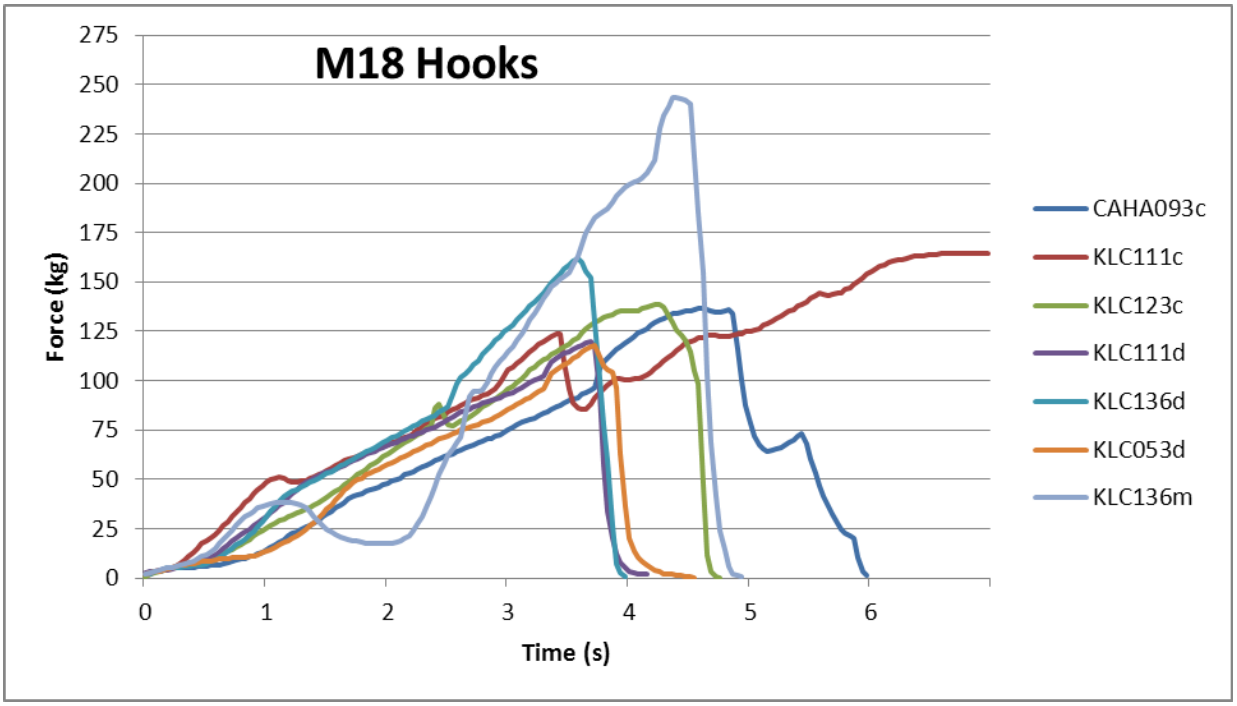


Figure 10. M-18 hooks in all specimens tested. M-18 hooks placed in soft tissues straightened at maximal loads between 118-162 kg. One test was terminated (KLC 111c)as the hook straightened and ran into a binding strap holding the head in place. The gape of the M18 hook was large enough to hook around to the deep surface of the mandible (KLC 136m); during this test the hook sustained a 243 kg load before breaking and fracturing the jaw (see Figures 18 and 25).

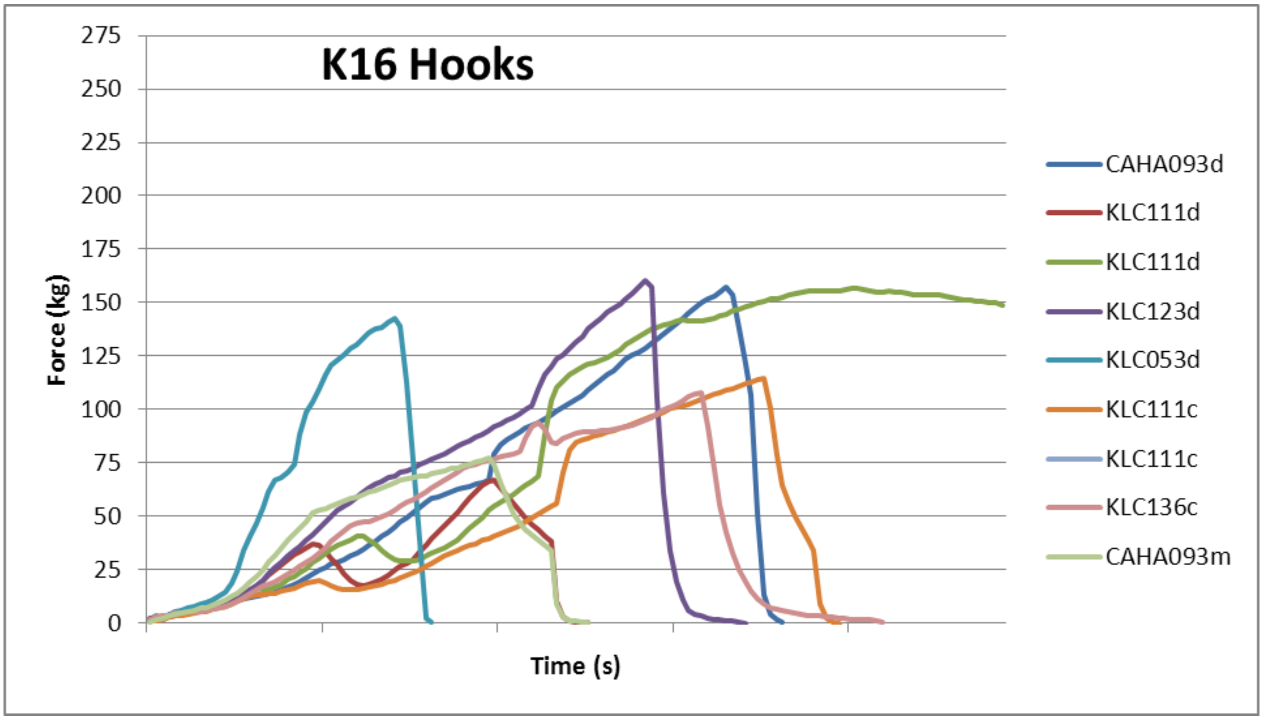


Figure 11. K-16 hooks in all specimens tested. K-16 hooks sustained maximum forces between 67-157 kg and then failed, usually by breaking. In one case (KLC 111d), the hook punctured through the lip tissue and sustained a 156 kg load before the test was terminated (see Figure 24). In one test (CAHA 093) the hook was placed on the dorsal surface of the mandible just behind the tooth row, but the K-16 did not have a large enough gape to hook around the jaw. During this test, the hook partially straightened, the barb broke, and both portions of the hook released from the jaw.

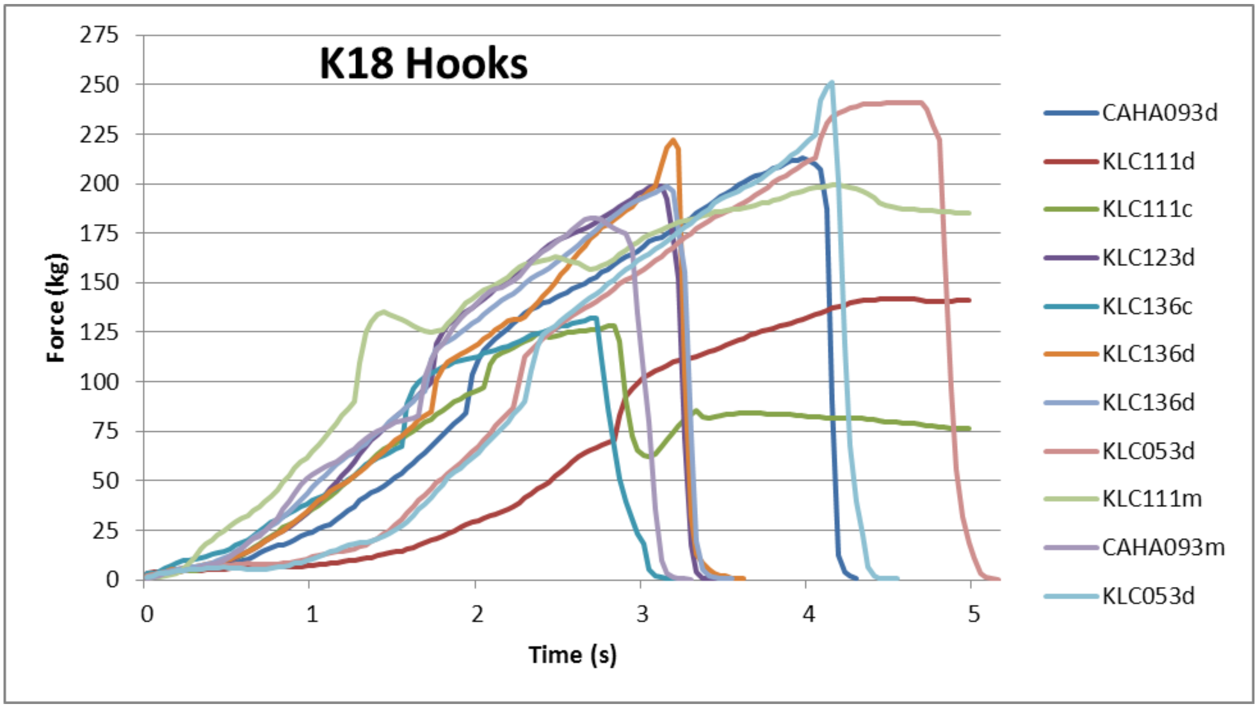


Figure 12. K-18 hooks in all specimens tested. K-18 hooks usually sustained higher maximum forces (141-251 kg) than any other hooks and typically failed by breaking. KLC 111 was the first specimen tested, and during the first round of tests, it was discovered that the K-18 hooks, if they did not shatter first, could lift the entire testing apparatus. All subsequent tests on KLC 111 and all other specimens were conducted on a more heavily weighted stanchion. The gape of the K-18 hook was large enough to hook around to the deep surface of the mandible, and in both experiments, fractured the jaw (KLC 111m and CAHA 093m)(see Figures 18 and 19).

Figures 13 – 17 present the data for all hooking experiments for each individual specimen.

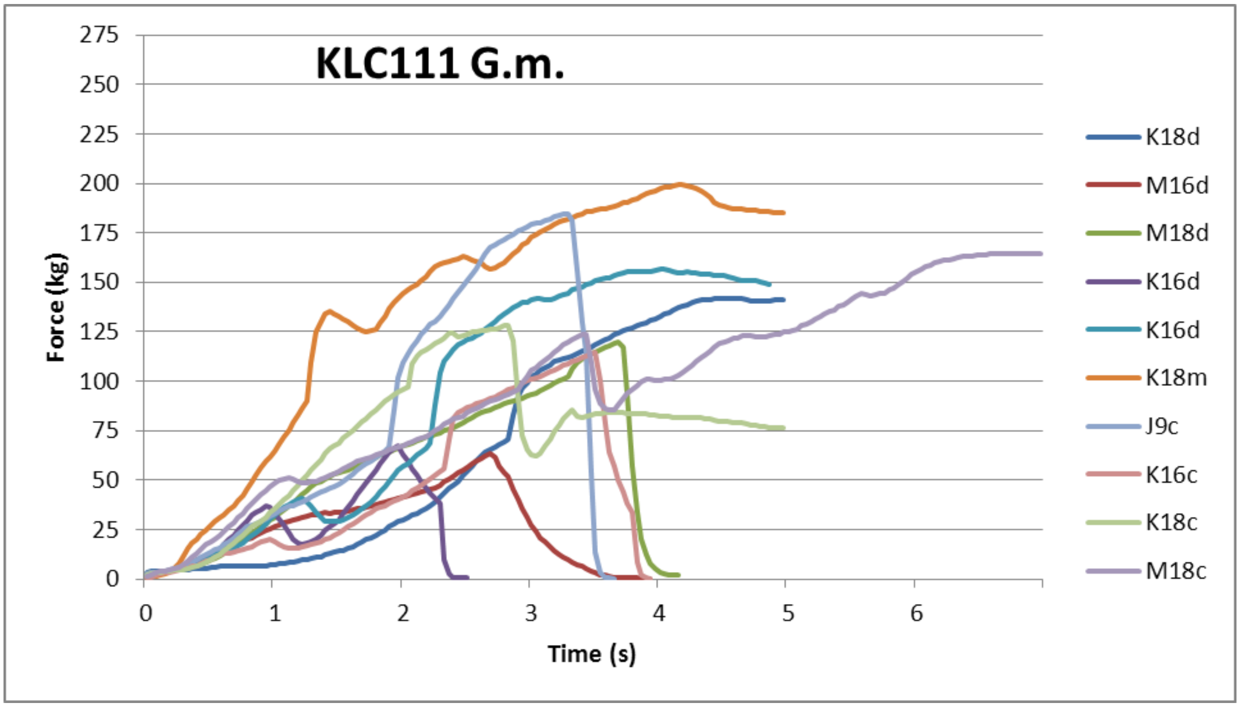


Figure 13. KLC 111 short-finned pilot whale hook tests.

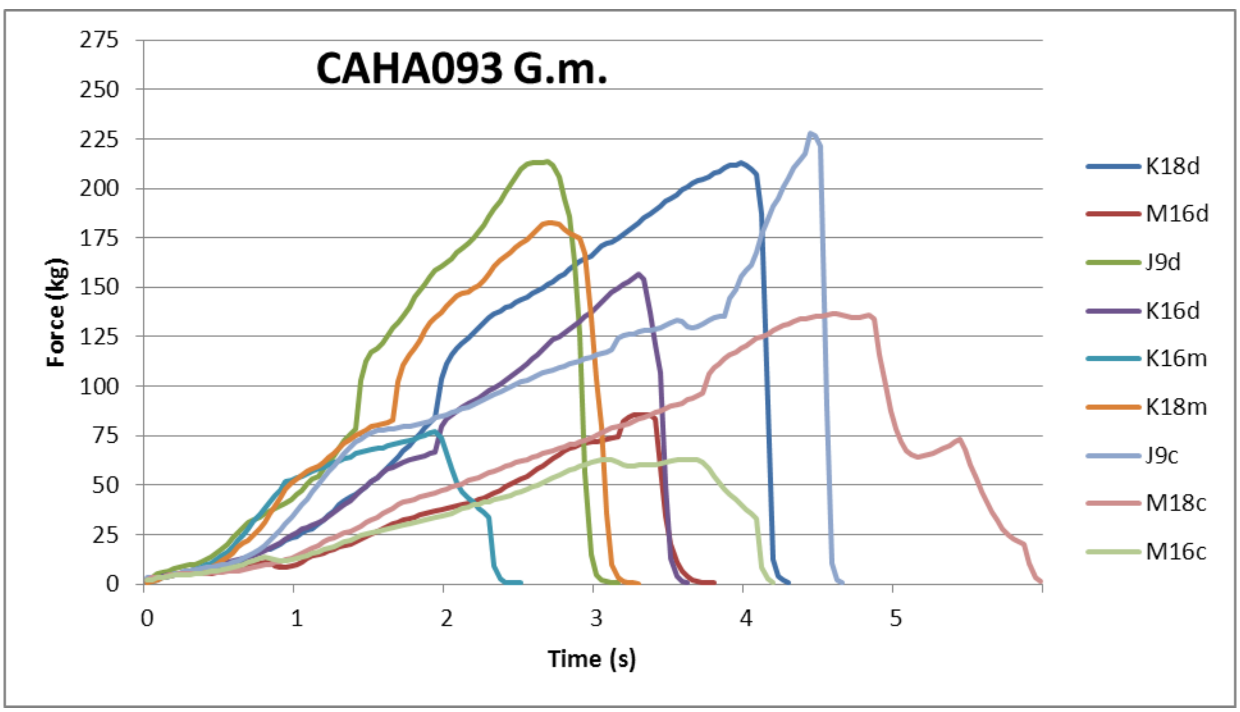


Figure 14. CAHA 093 short-finned pilot whale tests.

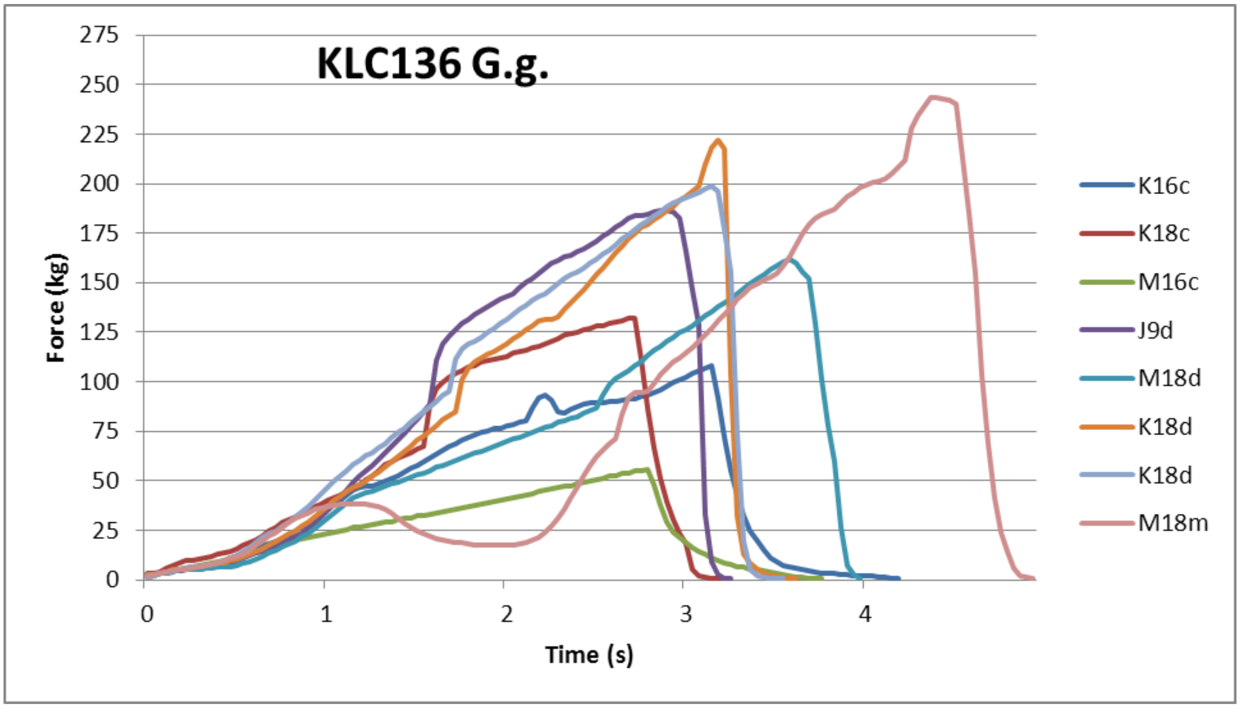


Figure 15. KLC 136 Risso's dolphin tests.

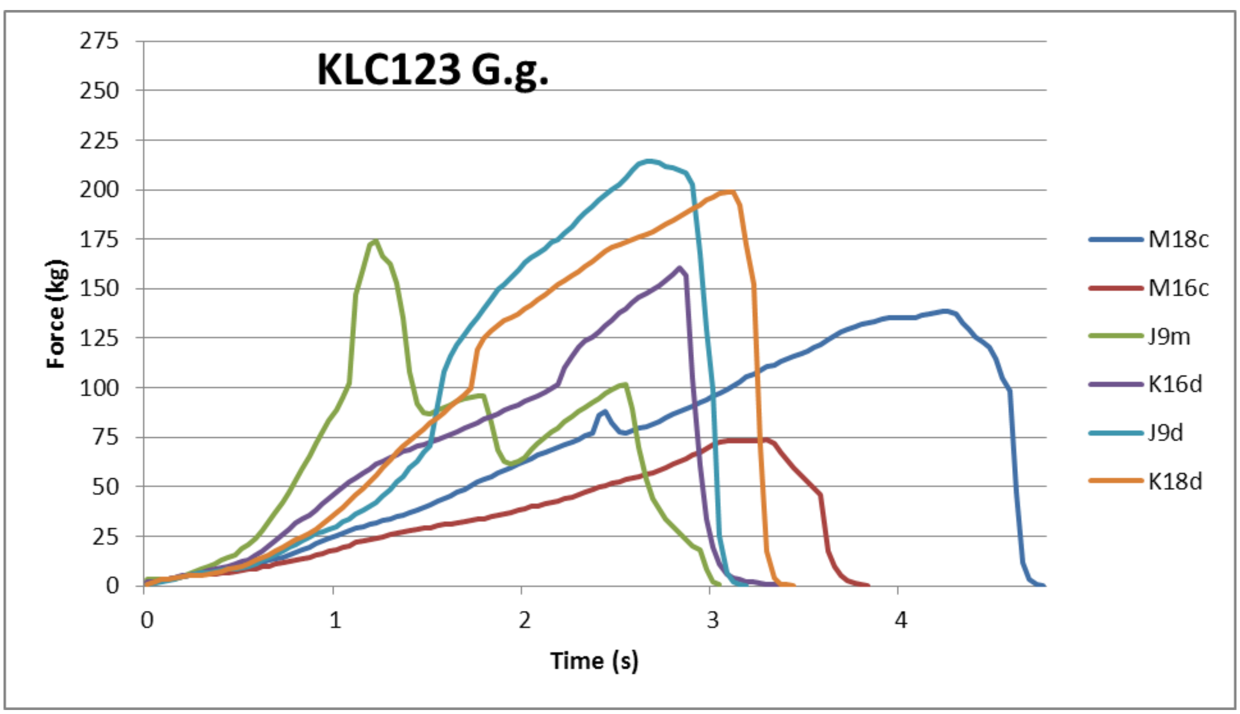


Figure 16. KLC 123 Risso's dolphin tests.

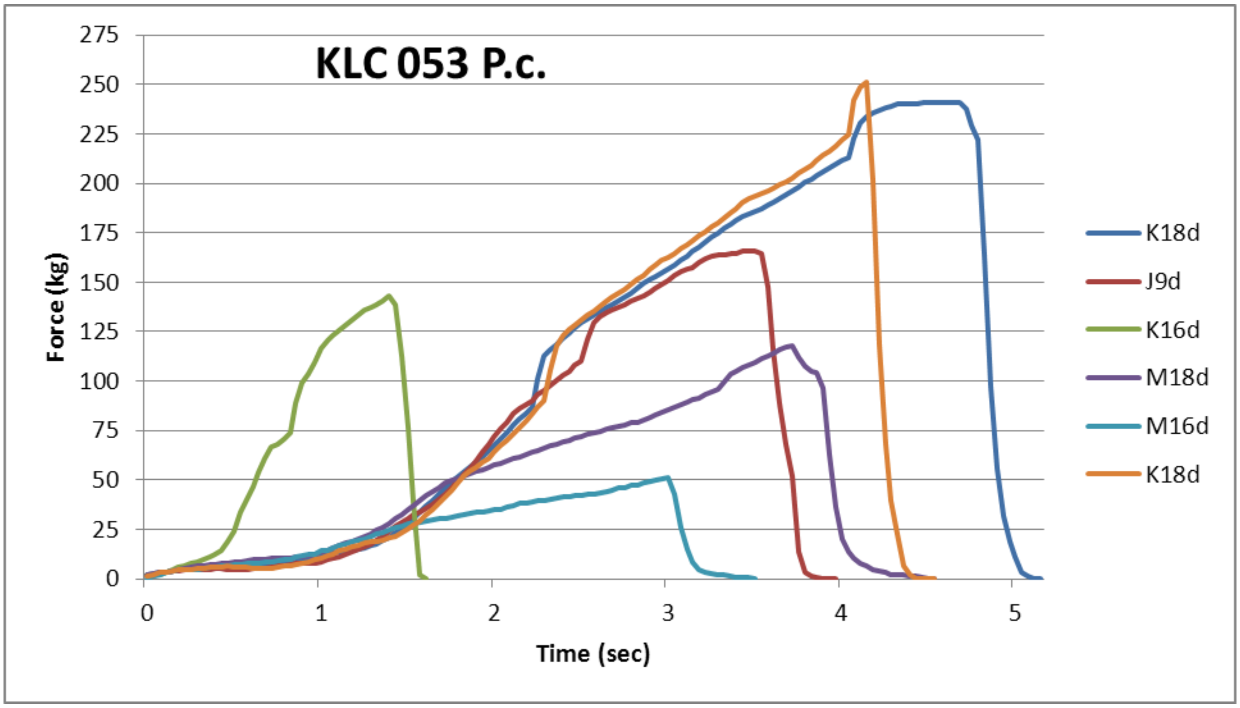


Figure 17. KLC 053 false killer whale tests.

Figures 18 – 20 illustrate the results of tests in which the hook was placed on the lingual (deep) surface of the mandible. These tests were run to determine if longline hooks placed around the mandible could cause bone fractures. Only M-18 and K-18 hooks (Figs. 18 - 20) had sufficiently wide gapes to secure the hook around the mandible. No other hooks used in the study could be secured around the mandible. In all three tests, hooks induced bone fractures.

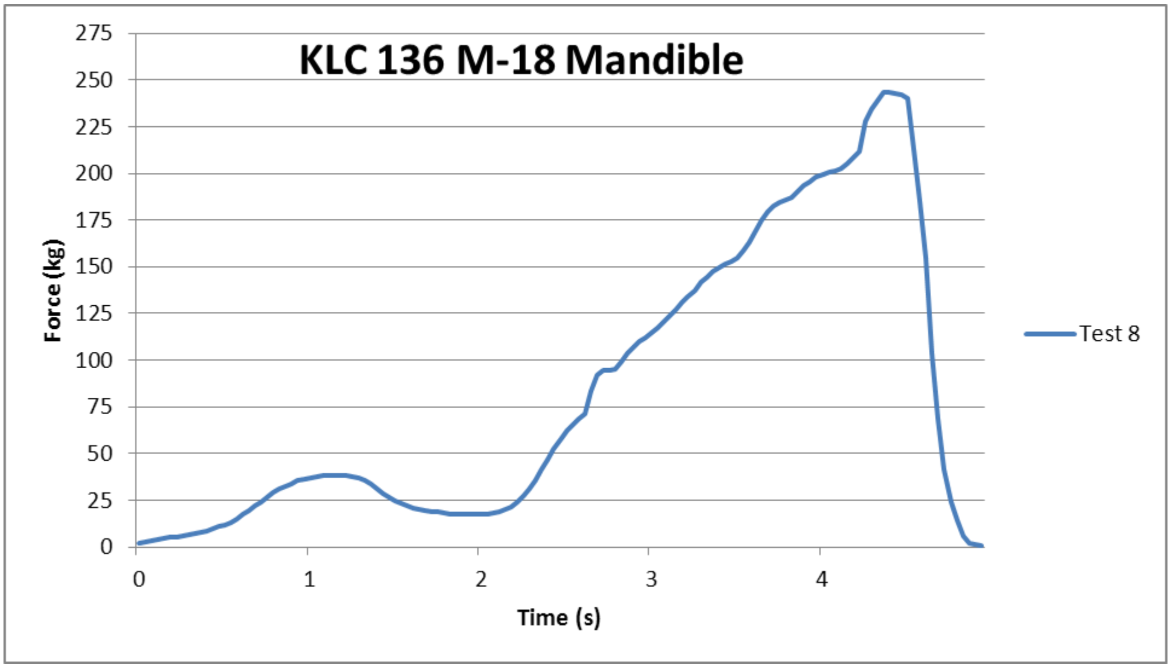


Figure 18. Fractured mandible M-18 test on KLC 136 Risso's dolphin. This hook sustained a 243 kg load before straightening, breaking and releasing; the tip of this hook remained within the fractured mandible.

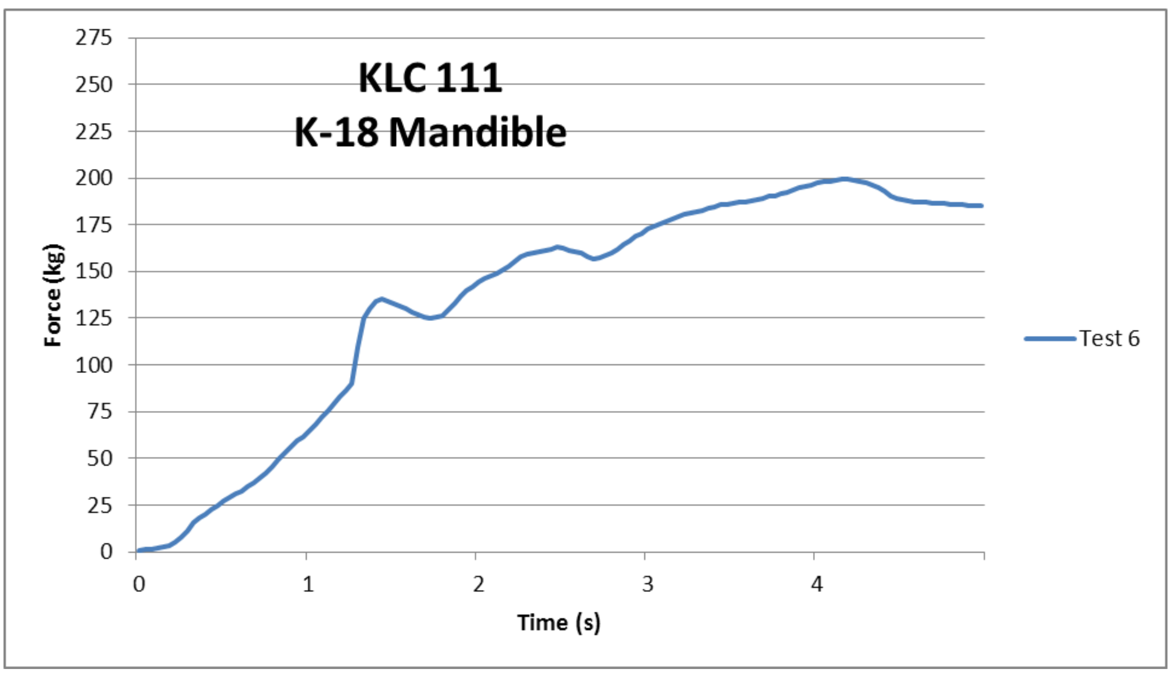


Figure 19. Fractured mandible K-18 test on KLC 111 short-finned pilot whale. This hook sustained a 199 kg load, remained intact, punctured into and fractured the jaw, and remained embedded in the jaw at the termination of the experiment.

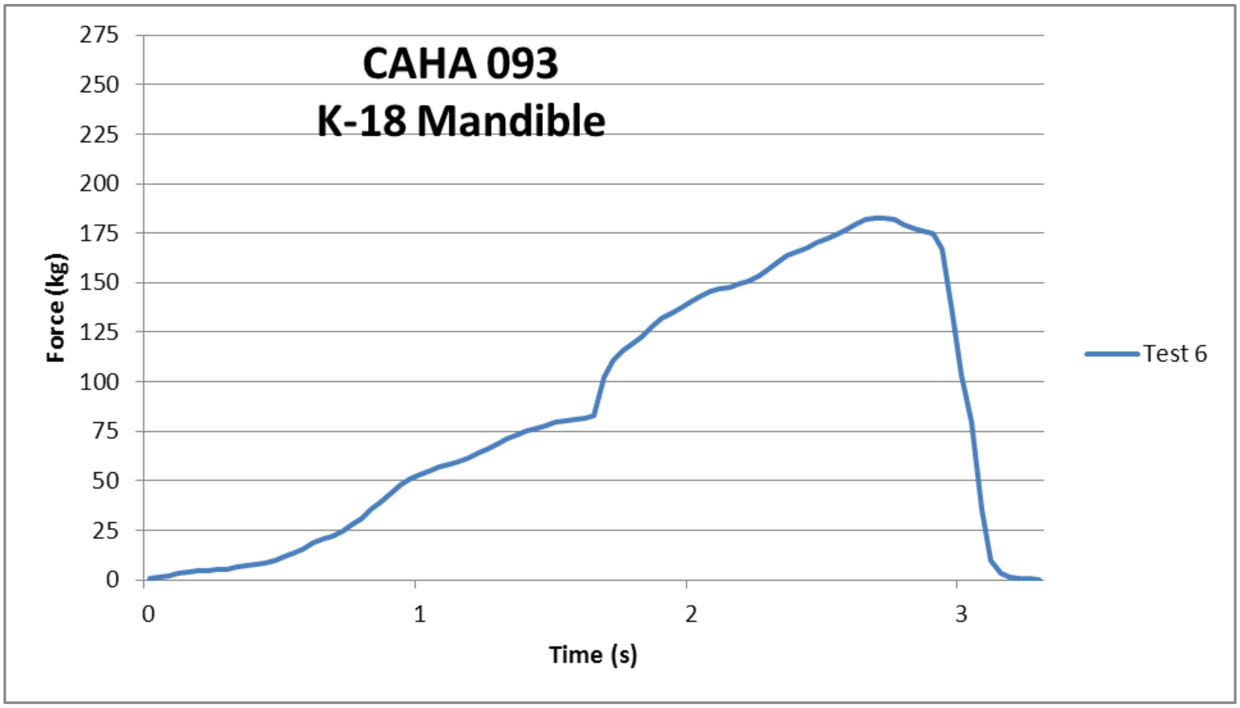


Figure 20. Fractured mandible K-18 test on CAHA093 short-finned pilot whale. This hook sustained a 183 kg load, partially straightened, then broke leaving the barb embedded within the fractured jaw bone.

Discussion

A series of commercially available hooks (see Figure 21) used by pelagic longline fisheries in both the Atlantic and Pacific were investigated. Tests were conducted first to characterize the straightening and/or breaking behavior of hooks prior to testing on odontocete cetaceans. Hooks varied in bending/breaking forces from approximately 50 – 225 kg, trending up from M-16, M-18, K-16, J-9 to K-18 hooks (see Figs. 3-7). Results of these isolated hook tests were used to assist in interpreting the behaviors of the hooks when tested in cetacean tissues.

The cetacean species tested - short-finned pilot whales (*Globicephala macrorhynchus*), Risso's dolphins (*Grampus griseus*) and false killer whales (*Pseudorca crassidens*) are known to depredate upon, and represent some of the most commonly taken species within, pelagic longline fisheries in the western North Atlantic (Bayse and Kerstetter 2010, Kerstetter 2012, Waring *et al*. 2012) and Hawaiian Pacific (Forney and Kobayashi 2007, Bigelow *et al.* 2012; Waring *et al.* 2012). For example, between 1992 – 2008, 83 pilot whales were scored as seriously injured, and five individuals were known to have died, through interactions with the Atlantic US pelagic longline fishery (Waring *et al*. 2012). Between 2006 – 2010, 18 false killer whales were scored as seriously injured, and one individual was known to have died, through interactions with the Hawaiian pelagic longline fishery (Waring *et al*. 2012). Understanding how longline hooks interact with the hard and soft tissues of these species is of value.

Thus, two different sets of tests were conducted on odontocete tissues. The first tests were performed by pulling the full suite of hooks through the soft tissue lip of the dorsal jaw. The intent of these tests was to determine how this lip tissue behaved in response to the hook mechanical tests and to gain insight into the probability that incidental hooking could cause soft tissue injuries as has been noted in stranding investigations (see Figure 22).

Overall, the forces required to pull the hooks through the soft tissue lip were dependent upon the hook type more than the species or the position along the lip. When pulled through odontocete lip tissue, the M-16, M-18 and J-9 hooks consistently bent throughout the entire length of the hook. The forces required to bend these hooks varied from 40 – 200 kg, depending upon the gauge of the hook (see Figs. 8 - 10). This bending pattern allowed the hook to bend beyond a 90^{o} angle, which opened the hook and exposed the extremely sharp tip barb. This change in hook shape allowed it to slice through the soft tissue (see Figure 23), rather than tear it. The sharp barb, thus, acted much like a knife to slice through the cetacean lip. Although how these wounds might heal in the wild is not known, complete wound healing from shallow, experimentally-induced lacerations has been documented to occur in the bottlenose dolphin (*Tursiops truncatus*) in as little as seven days (Bruce-Allen and Geraci, 1985).

In contrast, the forged carbon K-16 and K-18 hooks behaved much differently than these polished steel hooks. Although the shank of Korean hooks would straighten when pulled through soft tissues, their sharp bend would not, thus leaving the distal “hook” still in place (see Figs. 21 and 24). When placed in lip tissue, these hooks sustained higher levels of force (ranging from 67 – 251 kg) than their polished steel counterparts (see Figs. 11 and 13). To release, the hooks had to either (a) be pulled whole through the tissue, which caused a large section of tissue to be torn from the lip, or (b) break, which also resulted in large, jagged exit wounds. We hypothesize that these more destructive tissue injuries may take longer to heal than the slices delivered to soft tissue from the M-16, M-18 and J-9 steel hooks. For example, Corkeron *et al.* (1987) noted that shark bite wounds on free-swimming bottlenose dolphins could take weeks to months to heal completely. The K-16 and K-18 hooks appear to be a more brittle form of cast metal that fractures more readily than it bends. When tested in isolation, these hook types consistently tested to higher loads, but then catastrophically failed, sending shards of metal firing off around the Lab. When pulled through lip soft tissues, these hooks invariably broke at the level of the barb (see Figure 21), quite often leaving the barb tip imbedded in the lip tissue.

One additional set of tests was conducted to determine the probability of fracturing the mandible of these odontocetes. Although smaller hooks could be placed onto the dorsal surface of the jaw, only the K-16 and M-16 hooks were wide and long enough to be placed around the mandible and onto its lingual surface in these tests. These hooks were tested on both short-finned pilot whales and Risso’s dolphins (see Figs. 18-20). In all tests, the hook was strong enough to fracture the mandible. This information supports the determination of serious injury should a hook become entangled in the jaw of a small cetacean and supports the findings of mandibular fractures (see Figure 25) in short-finned pilot whales (Anderson *et al.* 2008, Oremland *et al*. 2010).

Management Considerations

Mechanical testing of biological tissues, and their interactions with fishing gear, can offer insights into how to mitigate the impacts of entanglement (*e.g.* Winn *et al.* 2008, Barco 2010). Such insights, though, must be tempered by acknowledging that mechanical tests cannot necessarily model the dynamic and event-specific features of such an entanglement. However, we believe that the results of this study suggest important points of consideration for future management decisions.

(1) The material from which the hook is made strongly influences its mechanical behavior within odontocete cetacean soft tissues. The more ductile, polished steel hook type (Mustad M-16, M-18, J-9) responded to being pulled through lip tissue by straightening along its entire length, thus opening and exposing the sharp barb at its tip. This change in shape permitted the barb to act like a knife and cut its way through the lip. The resulting injury was usually a linear, clean slice. In contrast, the forged carbon Korean hooks would not open completely, resulting in more jagged, tearing injuries to tissues, and sometimes leaving broken barb tip in the wound. The mechanical behavior of the Mustad polished steel hooks was also more consistent than that of the Korean forged hooks. *Thus, the polished steel Mustad hooks appear to result in less tissue damage, and respond to pulling forces in a more consistent manner, than do the Korean forged hooks.*

(2) The combined gape and bite of the hook make it more or less likely to be able to be hooked onto the deep, lingual surface of the mandible, which can result in fracturing the bone. The M-18 and K-18 hooks could be twisted and fit around the mandible of short-finned pilot whales and Risso's dolphins. When these hooks were pulled upon, they responded by fracturing the bone and either remaining entirely embedded, or breaking and leaving portions of the hook in the jaw. *Thus, hooks with larger gapes and bites, regardless of the material from which they are made, can hook into the lower jaw and fracture this bone.*

(3) The mechanical behaviors of these hooks were consistent across species tested. Although it is likely that the material properties of the odontocete lip vary slightly along its length, and across species, the results of this study indicate that the hooks behave similarly regardless of these differences. *Thus, it is likely that mechanical behaviors of the hooks tested here provide good models for their behaviors in other, similarly sized odontocetes.*

Taken together, the results of this study suggest that hooks formed by ductile polished steel, and of the smallest gape possible to prosecute a fishery, should be considered. These results only pertain, though, to minimizing (a) tissue damage to lip soft tissues and (b) the potential of a complete hooking of the jaw. How the size of the hook influences its potential for inflicting serious injury if ingested deeper into the cetacean is not known. Further mechanical tests that investigate alternative modes of hooking, should be investigated.

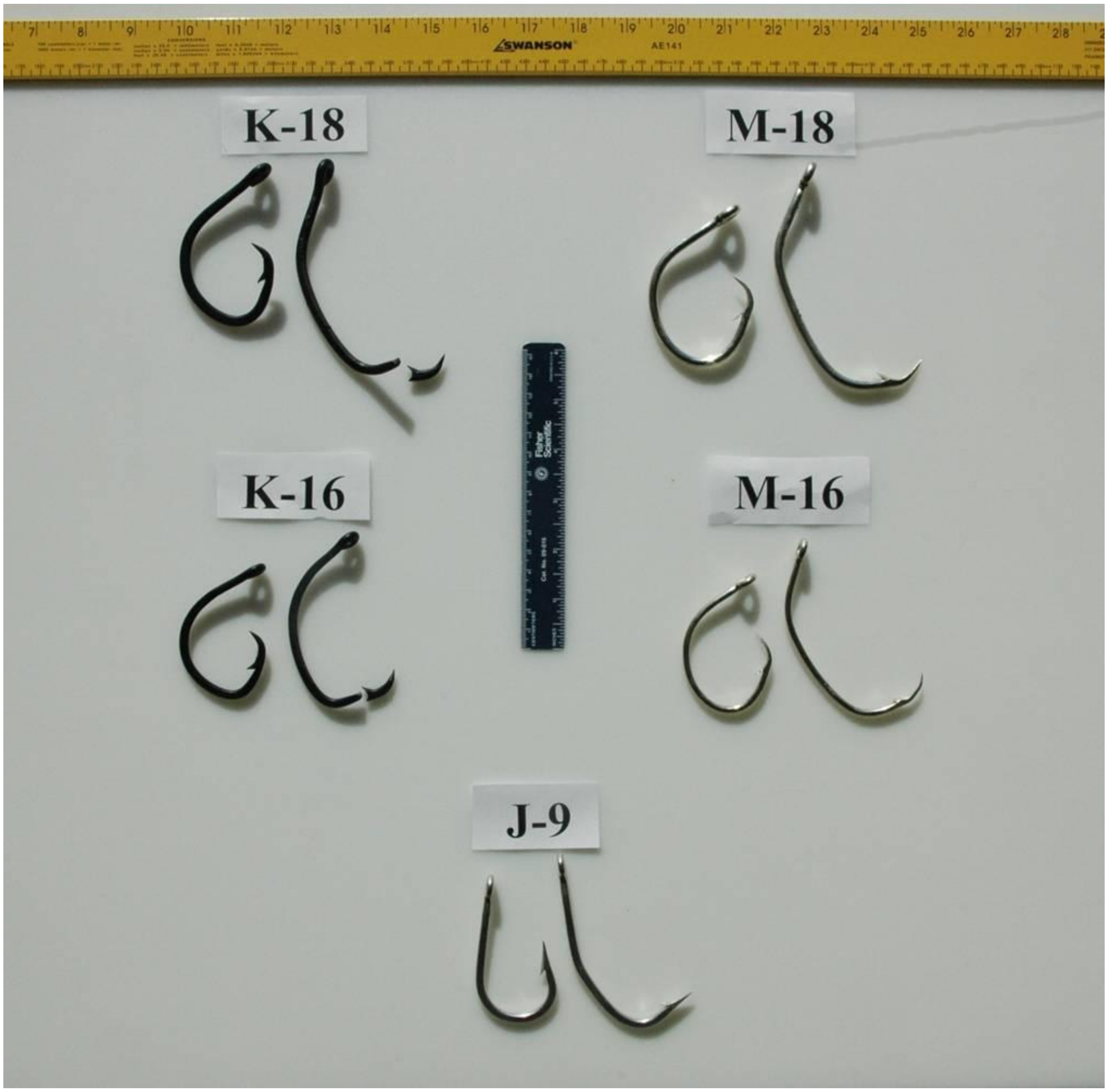


Figure 21. **Before and after views of hooks utilized in this study. The Korean carbon 16 and Korean carbon 18 hooks both bent in the long portion of the hook shank, but retained a sharp bend near the hook tip. This bend appears to prevent the hook from being released from soft tissue and allows for large forces (up to 250 kg of force) to build before cetacean tissues tear and/or the hook breaks at the barb. In contrast, the Mustad 16/0 and Mustad 18/0 and Mustad J-9 hooks straighten more completely; this deformation exposes the barb and allows it to slice through, rather than tear, the lip tissue. These hooks appear to cut themselves free to permit the hook to be shed.**

Figure 22. Short-finned pilot whale dorsal lip shows evidence with tissue injury consistent with longline fisheries interaction. (Photo courtesy of 2005 multi-species stranding event.)

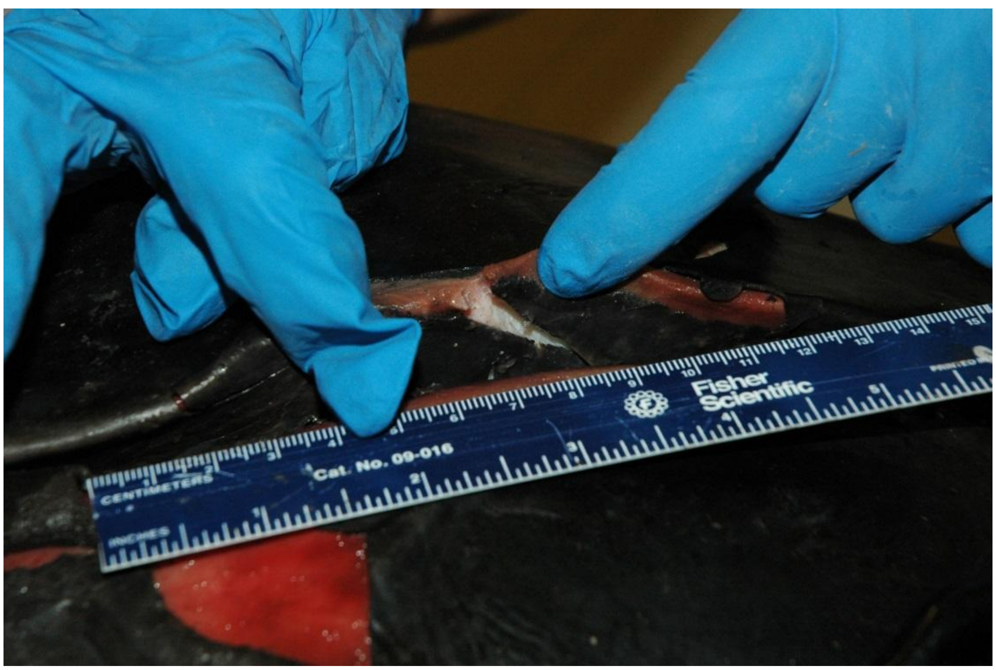


Figure 23. The dorsal lip of a short-finned pilot whale showing the slice created in the soft tissue as the Mustad 16/0 hook straightens and slices through the lip.

Figure 24. View of the tissue of dorsal caudal lip of a short-finned pilot whale with a Korean Carbon 16 hook being pulled to 156 kg of force. The soft tissues resist tearing even under this high load.

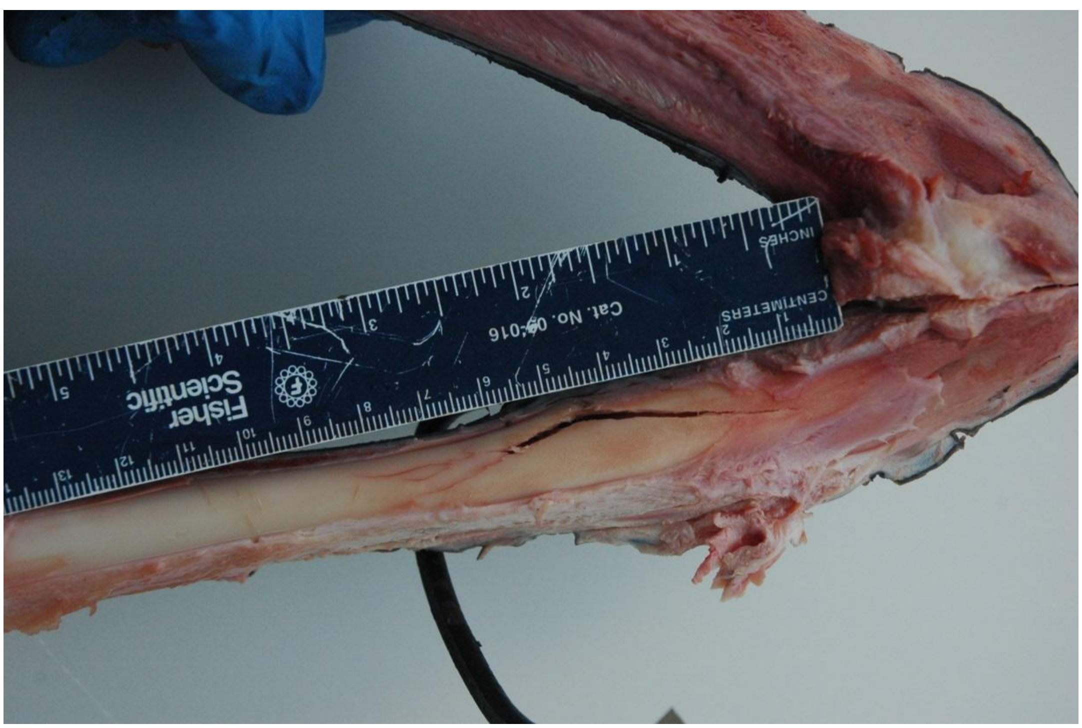


Figure 25. Image of the fractured jaw of the short-finned pilot whale KLC 111 with K-18 hook (see Figure 18 for test force data).

Acknowledgments

We would like to thank Karen Clark of the North Carolina Wildlife Resources Commission and Paul Doshkov of the National park Service, Cape Hatteras National Seashore for their tireless efforts in responding to and collecting marine mammal strandings on the Outer Banks. Dr. David Kerstetter, Nova Southeast University, provided significant insights into the pelagic fishery and providing the appropriate hooks to be tested. The Pelagic Longline Take Reduction Team provided excellent discussions and suggestions over the course of this study. Tiffany Keenan-Bateman assisted with the mechanical tests. Stranding response at UNCW was funded by John H Prescott Stranding Grants (NOAA) to UNCW. This work was conducted under a Stranding Agreement from NOAA Southeast Region to UNCW. Funding for this work was provided by the Consortium for Wildlife Bycatch Reduction.

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Outreach Activities

WAM travelled to St. Petersburg, Florida to participate in the Pelagic Longline Take Reduction Team meeting from 21 -23 August and there presented the weak hook testing approach and preliminary results from short-finned pilot whales. The presentation was well-received and spurred discussion among the fishing industry, industry representatives, the environmental community and scientists.

WAM presented a webinar to the Hawaii Pelagic Longline TRT on 30 May 2013 detailing the hook testing results for pilot whales and the one false killer whale. The team was very interested in the results of the weak-hook testing and was interested in additional hook and gear testing. There was interest in how much damage is caused as gear is ingested but those results are beyond this round of testing.