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Identification Guide and Iconography of Eastern Pacific Hybrid Abalone Shells (Genus *Haliotis*) Part 1 of 2

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ABSTRACT There are seven species of *Haliotis* that inhabit the rocky coastline and offshore islands in the Eastern Pacific Ocean and hybridization has been observed, though very rarely, among them. This manuscript along with photo images of known hybrid specimens will serve as a guide to identifying hybrid abalone shells of this area.

KEY WORDS Haliotidae, *Haliotis*, abalone, Eastern Pacific, hybrid abalone

INTRODUCTION The following seven abalone species are found on the Eastern Pacific Ocean coastline from Alaska, USA, to Baja California, Mexico:

Haliotis	**Common name**
corrugata W. Wood, 1828	Pink or Corrugated abalone
cracherodii Leach, 1814	Black abalone (currently an endangered species in USA)
fulgens Philippi, 1845	Green abalone
kamtschatkana Jonas, 1845	Pinto (northern form) or Threaded (southern form) abalone
rufescens Swainson, 1822	Red abalone
sorenseni Bartsch, 1940	White abalone (currently an endangered species in USA)
walallensis Stearns, 1899	Flat abalone

In 1954, Owen began observing hybrid abalone shell specimens from commercial shell piles. While a commercial abalone diver between 1959 and 1965, Owen harvested hybrid specimens and his observations were published (Owen *et a*l., 1971). Owen's career moved on to working for 14 years in an aquaculture facility where he was able to conduct hybridization experiments in the laboratory. These experiments were documented in 1972 but the results only published recently (Owen & Meyer, 2015).

Owen self-collected most of the hybrid shell specimens that exist in his collection either from commercial shell piles or while commercially diving. Owen gained a few more shell specimens from commercial diving colleagues. Most of the Eastern Pacific Ocean abalone shells that Owen confirmed as hybrids reside in Owen's collection with a few deposited in the Los Angeles County Museum as type specimens. Owen is aware of a few more hybrid specimens in private collections.

Most of the hybrids Owen amassed in his collection originated in Southern California, USA and Baja California, Mexico. While a commercial abalone fishery still exists in Mexico, due to a marked decline in population numbers, a moratorium was placed on the California fishery south of San Francisco in 1997. As such, abalone is no longer being harvested in mass quantities. Few hybrid

abalone have been found north of Southern California. Acquiring hybrid abalone shell specimens at the present time from the ocean is unlikely. What follows is a guide to identifying hybrid abalone shells of the Eastern Pacific Ocean.

For *Haliotis* species with associated subspecies (*corrugata*, *cracherodii*, and *fulgens*), any hybrids discussed and shown in the Figures are of the parent's nominate subspecies and for brevity, labeling will be provided only to species hierarchy. Also for brevity, all specimens pictured are from California, USA, unless from Mexico in which case that will be explicitly labeled within the Figures. All specimens are from Owen's personal collection unless labeled otherwise within Figures.

Abbreviation of Collections: BOC: Buzz Owen Collection, Gualala, CA; DPC: Don Pisor Collection, San Diego, CA; JMC: Jim Marshall Collection, Carpinteria, CA; LACM: Los Angeles County Museum of Natural History, Los Angeles, CA. All collections located in USA.

Materials and Methods: Shell specimens photographed were cleaned with any of the following tools: Xacto tool with #11 blade, dental scalers, wire brushes, tooth brushes. Shell specimens were slightly moistened with mineral oil. They were then photographed with either Canon A65OES or Nikon Coolpix 5700 digital cameras. The images were processed in Adobe Photoshop Version 6 and placed on black plates.

Shells Examined: Thousands of shells of each conspecific species.
Haliotis corrugata x *H. rufescens*: 49
Haliotis corrugata x *H. walallensis*: 26
Haliotis corrugata x *H. fulgens*: 25
Haliotis corrugata x *H. sorenseni*: 10
Haliotis corrugata x *H. kamtschatkana*: 3
Haliotis corrugata x *H. cracherodii*: 1

DISCUSSION

The most recent comprehensive examination of Family Haliotidae was published in Geiger & Owen (2012) and in that publication, each species was illustrated with at least 10 specimens. The specimens were carefully chosen to show the variability found within a species, subspecies, or form with respect to morphology and coloration.

A hybrid specimen has a blend of *multiple* parent species characteristics such that it does not fall within the normal description of a conspecific species. When abalone are 50 mm or less in size, it is sometimes difficult to accurately identify the species for conspecific specimens but even more so for hybrids. For abalone species that form a muscle scar, that development does not begin taking place until the shell is approximately 100 mm. The complexity, coloration, and pattern of the muscle scar can be key factors in identifying which parent species comprise a hybrid specimen. Large mature hybrid shells best demonstrate the characteristics of both parent species.

Table 1 summarizes the number of hybrid abalone shell specimens known to have come from natural populations in the Eastern Pacific Ocean. Part 1 of this 2-part hybrid discussion will address only the hybrids of *Haliotis corrugata* - the shaded column in Table 1. *Haliotis corrugata* is the only abalone species known to hybridize with *all* other Eastern Pacific Ocean species.

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Haliotis							
corrugata	*corrugata*						
cracherodii	1	*cracherodii*					
fulgens	25	10	*fulgens*				
kamtschatkana	3	0	0	*kamtschatkana*			
rufescens	49	0	2	35	*rufescens*		
sorenseni	10	0	0 *	6	>1000	*sorenseni*	
walallensis	26	0	0	1	6	2	*walallensis*

TABLE 1: Natural population hybrid abalone shell specimen numbers
***** This hybrid combination has been cultured but no specimens exist from natural populations.

What follows are some general diagnostic characteristics that usually apply to *H. corrugata* hybrids. Most hybrids of *H. corrugata* exhibit oblique parallel ribbing between the row of holes and the columella. This feature appears strongly on a conspecific *H. corrugata* as shown in Figure 1 A. This ribbing is more muted in the hybrids since most other species don't exhibit this characteristic. Many hybrids of *H. corrugata* exhibit a noticeable colorful growing edge which is somewhat serrated along the columella near the row of holes. Figure 1 B highlights this characteristic for a conspecific *H. corrugata*. If this characteristic is noted on a suspected hybrid specimen, one of the parents is very likely *H. corrugata* though not all hybrids of this species exhibit this attribute. Figure 1 C depicts alternating thick and thin rounded spiral cords inherent to *H. corrugata* sculpture particularly during the juvenile phase of growth and this often is found in the hybrids though somewhat altered by the other parent species (the thickness of the cords, for example). One characteristic of most *H. corrugata* that is much reduced in all the hybrids is the prosocline ridge sculpture as shown in Figure 1 D. As *H. corrugata* is a species that has a muscle scar, many mature hybrids of this species exhibit at least a hint of muscle scar development as illustrated in the Figures.

Hybrids of *Haliotis corrugata* are the most readily identified and this stems from the species being the most sculpted of the Eastern Pacific Ocean abalone taxa. The first row in Figure 2 shows a conspecific *H. corrugata* that exhibits all the general diagnostic characteristics. Ventral features to note are the muscle scar and the thick colored and serrated growing edge that

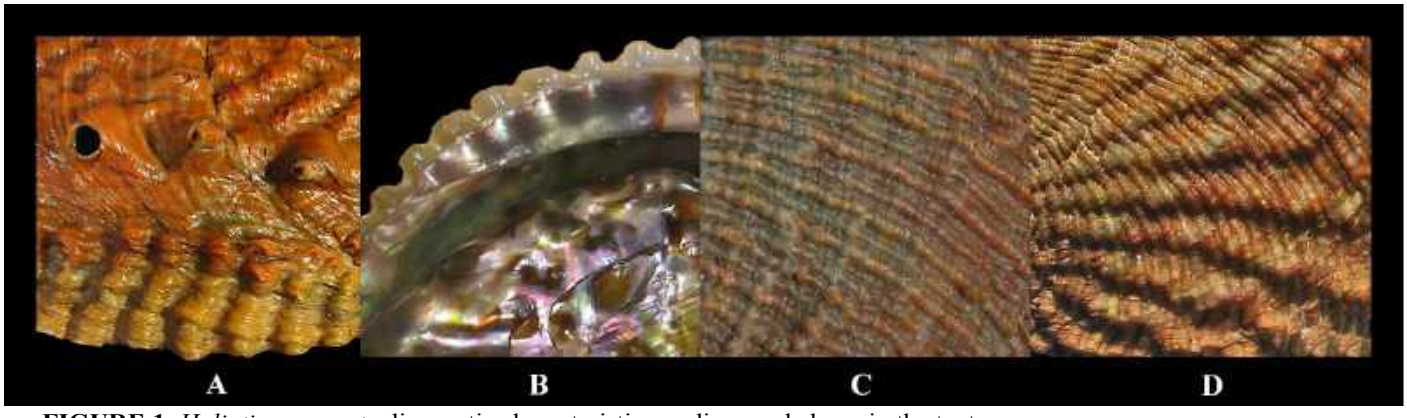

FIGURE 1. *Haliotis corrugata* diagnostic characteristics as discussed above in the text.

is evident over most the entire circumference of the shell. The middle row of Figure 2 shows a 154 mm hybrid abalone shell which would be considered an adult size regardless of species. It is by a process of recognition as well as elimination that will be discussed shortly in which the parent species can be determined revealing this specimen is a *Haliotis corrugata* x *H. walallensis*. A *H. walallensis* is shown in the third row of Figure 2.

The specimen in the middle row of Figure 2 is a hybrid because it does not fit the description of any conspecific abalone. The dorsal sculpting of this hybrid specimen is more textured than any of the Eastern Pacific Ocean species except for *H. corrugata*, which is, hence, one of the parent species. Though subtle, the oblique parallel ridges between the row of holes and columella are also indicative of *H. corrugata*. Given that one of the parent species is definitely *H. corrugata*, then the other parent species effectively introduces more and smaller holes, suppresses the muscle scar almost entirely, reduces the growing edge to a very thin margin, decreases the depth of the shell, and mutes the corrugations. The only other species that would induce *all* of these characteristics is *H. walallensis*. *Haliotis corrugata* usually has 2 to 4 open holes while *H. walallensis* normally has 6 to 8; the hybrid combination usually has 4 to 6 open. The hybrid contains a true amalgamation of multiple characteristics of both parents and exhibits an absence of some characteristics of one or the other parent (*e.g.* no longer having a *H. corrugata* thick growing edge or muscle scar as well as none of the dorsal chevron-patterning of *H. walallensis*). Figures 3 and 4 illustrate 21 additional specimens of the *H. corrugata* x *H. walallensis* hybrid.

The remainder of this paper will discuss all of the remaining *H. corrugata* hybrids and provide some guidelines, but not rules, of features that would help a collector determine if they are indeed in possession of a hybrid *H. corrugata* shell specimen.

Haliotis corrugata x *H. rufescens*

This combination is the most common of *H. corrugata* hybrids and the second most common overall (*see* Table 1). The general diagnostic characteristics are very applicable to this hybrid combination: at least subtle oblique parallel ridges usually exist between the row of holes and columella, the growing edge is usually fairly thick and often serrated at the terminus of the columella, a muscle scar is present in mature specimens, as well as spiral alternating thick and thin rounded cords, with only a little development of prosocline ridge sculpture. More specifically, this hybrid possesses a fairly heavy shell, exhibits holes of large aperture but not quite as fluted as conspecific *H. corrugata*, maintains a colorful and thick growing edge when in growth phase of life, yet curiously often has a less complex muscle scar than either of the parent species - usually tending more to resemble *H. rufescens*. Stated fairly simplistically, this hybrid often more resembles *H. rufescens* with a lot of rough sculpture/texturing on the dorsum, but careful examination reveals that multiple characteristics of both parents are present. *Haliotis corrugata* usually has 2 to 4 open holes, while *H. rufescens* normally has 3 to 5. Most specimens of the hybrid have 3 to 4 open. A single specimen of this hybrid combination is shown with representative parent species in Figure 5. Figures 6 and 7 illustrate 20 additional examples of this hybrid combination.

Haliotis corrugata x *H. fulgens*

Relative to the general diagnostic characteristics, this hybrid often exhibits subtle oblique parallel ridges between the row of holes and the columella though in some specimens this is not visible, the spiral alternating thick/thin rounded

cords is overt, and the prosocline ridge sculpture is absent. The hybrid counters one general diagnostic characteristic relative to the growing edge - it is not thick but rather thin and serrated and does not always adorn the terminus of the columella. More specifically, this hybrid has a shell depth that is intermediate between the deeper cup of *H. corrugata* and the flatter arch of the *H. fulgens*, there are an intermediate number of open holes (generally 4 to 5; *H. corrugata* usually has 2 to 4 open, while *H. fulgens* most frequently has 5 to 7) that are of intermediate size and fluting, and the muscle scar is fairly complex in mature specimens and conflicted between the attributes of the parent species. *Haliotis fulgens* often exhibit peppered white speckling in a spiral swath spanning from the row of holes toward the apex of the shell and this color patterning is absent in the *H. corrugata* x *H. fulgens* hybrid. There are two additional specific diagnostic characteristics that this particular hybrid combination exhibits. The first is a dorsal surface that is very often marked with areas of orange to reddish-brown color that reflect a diet high in red algae. These areas will generally vary from a light to darker color due to a variable amount of brown algae being consumed by the animal during the period the shell increment was being deposited. This orange to red-brown color will frequently alternate with areas of green to blue-green banding which occur when the animal was consuming primarily brown algae. This is very common to *H. corrugata*, but very rarely seen in *H. fulgens*, which is generally of an overall brown color, with occasional green diet-induced banding. Additionally, specimens of the hybrid exist which are almost solid orange. Two such specimens are illustrated on the bottom row of Figure 10 (this Figure contains selected specimens which exhibit major areas of this red/orange/brown color). The second diagnostic characteristic is the pinkish gray (to blue-gray) color of the ventral surface of the hybrid as it approaches maturity - this color becomes progressively dull and non-reflective with age (Figure 8.2). This is a strong feature of *H. corrugata* and is very different from the bright green to blue-green color of *H. fulgens* (Figure 8.4). Sub-adults and younger specimens will not exhibit this feature, and it is generally seen only in mature shells of *H. corrugata* and the hybrid. As with the other Eastern Pacific hybrids, this cross combines characteristics of both parent species while obviously representing neither. Two representative specimens of this hybrid are illustrated with the parent species in Figure 8. Figures 9 and 10 illustrate 20 additional examples of this hybrid combination.

Haliotis corrugata x *H. sorenseni*

Relative to the general diagnostic characteristics, this hybrid does exhibit subtle oblique parallel ridges between the row of holes and the columella, the spiral alternating thick/thin rounded cords is overt but on a thread-sized scale, and the prosocline ridge sculpture is absent. This hybrid counters one general diagnostic characteristic and that is relative to the growing edge - it is not thick but rather thin - however a serrated pattern does appear along the columella in most specimens. More specifically, as it approaches maturity, this hybrid has a shell depth that is intermediate between the deep cup-like proportions of *H. corrugata* and the even deeper arch of *H. sorenseni*, the holes are large and fluted like both parent species and of intermediate number (*H. corrugata* 2 to 4; *H. sorenseni* 3 to 5; hybrids 3 to 4), and the overall shape of the shell is quite round which is common to the parent species. The muscle scar is usually highly suppressed by the *H. sorenseni* parent. *Haliotis sorenseni* sometimes exhibits peppered white speckling throughout the dorsum and sometimes an orange spiral color band along the row of holes when less than 50 mm - however

such color patterning is absent in the *H. corrugata* x *H. sorenseni* hybrid; perhaps because so few specimens exist this pattern has yet to be observed. A single specimen of this hybrid combination is shown with representative parent species in Figure 11. Figure 12 illustrates all 10 shells known to exist of this hybrid combination.

Haliotis corrugata x *H. kamtschatkana*

Three specimens exist of this hybrid combination and none were observed with the living animal. Recognition and process of elimination methodologies were used to identify the parent species. The dorsal sculpting of the hybrid specimens is more textured than any of the Eastern Pacific Ocean *Haliotis* species except for *H. corrugata*, which identifies one of the parent species. Though subtle, the oblique parallel ridges between the row of holes and columella are also indicative of *H. corrugata*. Given that one of the parent species is *H. corrugata*, then the other parent species effectively introduces more and smaller holes, suppresses the muscle scar almost entirely, reduces the growing edge to a very thin margin, increases the depth of the shell, elongates it to a more oval shape, and mutes corrugations while maintaining the strong cording. The only other species that would induce *all* of these characteristics is *H. kamtschatkana*. The one *H. kamtschatkana* characteristic completely unaccounted for is color patterning on the dorsum but this has been the case with all of the *H. corrugata* hybrids - diet induced color changes are observed but patterning of any sort is muted to the point of nonexistence. The three known hybrids have 4 to 5 open holes; *H. corrugata* typically has 2 to 4, while the southern form of *H. kamtschatkana* generally has 4 to 7. All three specimens of this hybrid combination are shown with representative parent species in Figure 13.

Haliotis corrugata x *H. cracherodii*

There is only one known specimen of this extremely rare hybrid and the animal was not observed. With respect to the general diagnostic characteristics, all apply: oblique parallel ridges between row of holes and columella, thick growing edge which borders the columella, alternating spiral thick/thin cords, and no prosocline ridge sculpture. More specifically, this one hybrid is a round, fairly deep and heavy shell possessing an intermediate number of open holes (*H. corrugata* has 2 to 4, *H. cracherodii* 5 to 8, the unique hybrid has 5) that are of intermediate size and fluting, with the muscle scar being suppressed by the *H. cracherodii* parent. In this case, the dark dorsum of the shell is also a strong indicator that *H. cracherodii* is one of the parent species. From work Owen did in an aquaculture laboratory, *H. cracherodii* is least likely to hybridize with other *Haliotis* species (sperm is actually repulsed from ovum - see Owen & Meyer 2015) which further emphasizes the rarity of this single specimen. The only known example of this hybrid combination is shown with representative parent species in Figure 14.

CONCLUSION

Hybrid abalone specimens are known to occur very rarely in natural populations. They can be created in a laboratory setting and can involve more than just two parent species (Owen & Meyer, 2015). The epipodial characteristics of the live animal provides the strongest indications that hybridization has occurred provided the specimen has matured to the point that characteristics of both parent species have become evident (usually about 50-75 mm). This paper has provided diagnostic information for abalone shells that do not adhere to conspecific characteristics. With the photo plates, examples are shown for the Eastern Pacific Ocean abalone species that have

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hybridized with *Haliotis corrugata*. Part 2 of this series will address the remaining hybrid combinations not yet discussed and pictured.

ACKNOWLEDGEMENTS

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FIGURE 2. Top row: *Haliotis corrugata*. Anacapa Island. 155 mm. Center Row: *H. corrugata* x *H. walallensis*. Baja California, Mexico. 152 mm. Bottom row: *H. walallensis*. Baja California, Mexico. 142 mm. All specimens live-taken by commercial abalone diving prior to 1965.

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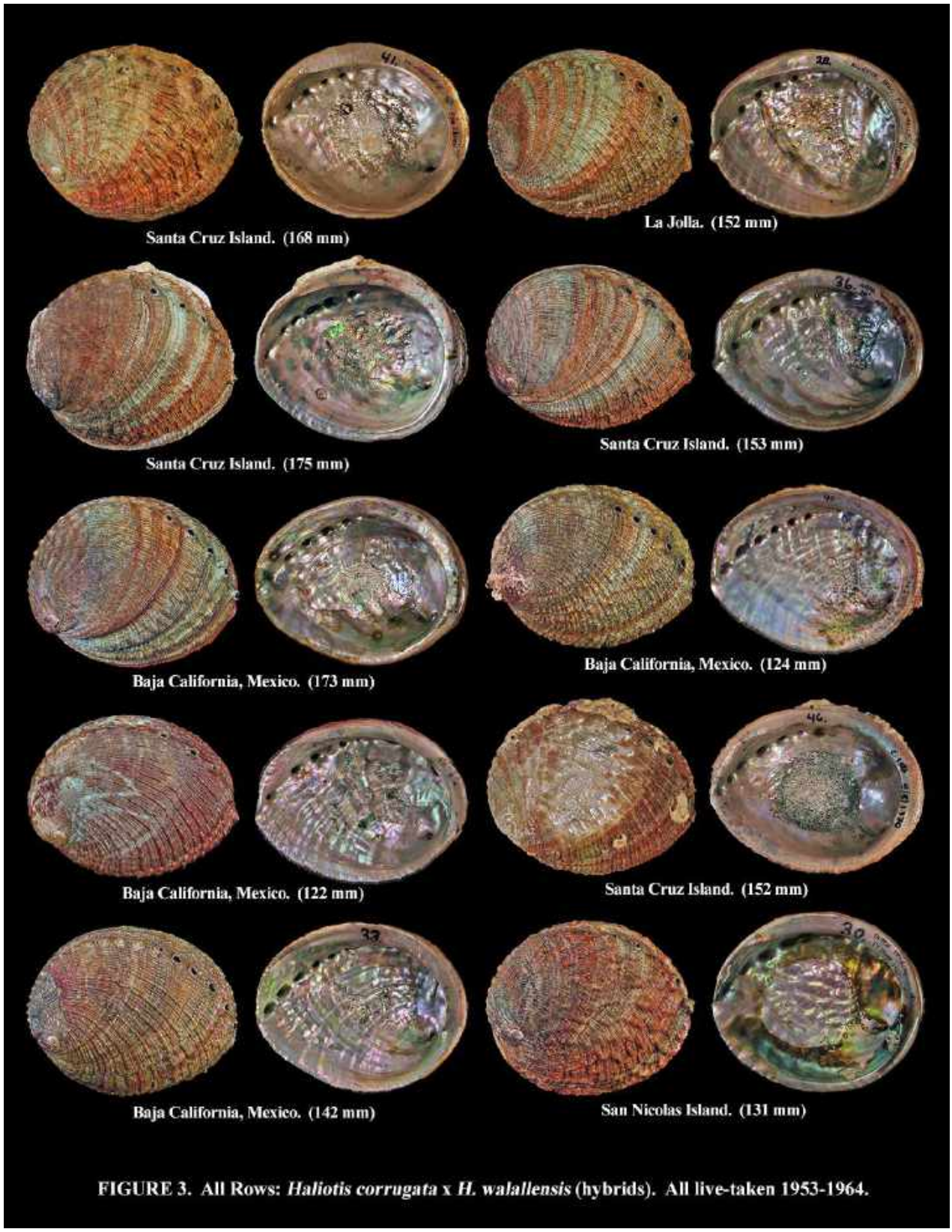

FIGURE 3. All Rows: *Haliotis corrugata* x *H. walallensis* (hybrids). All live-taken 1953-1964.

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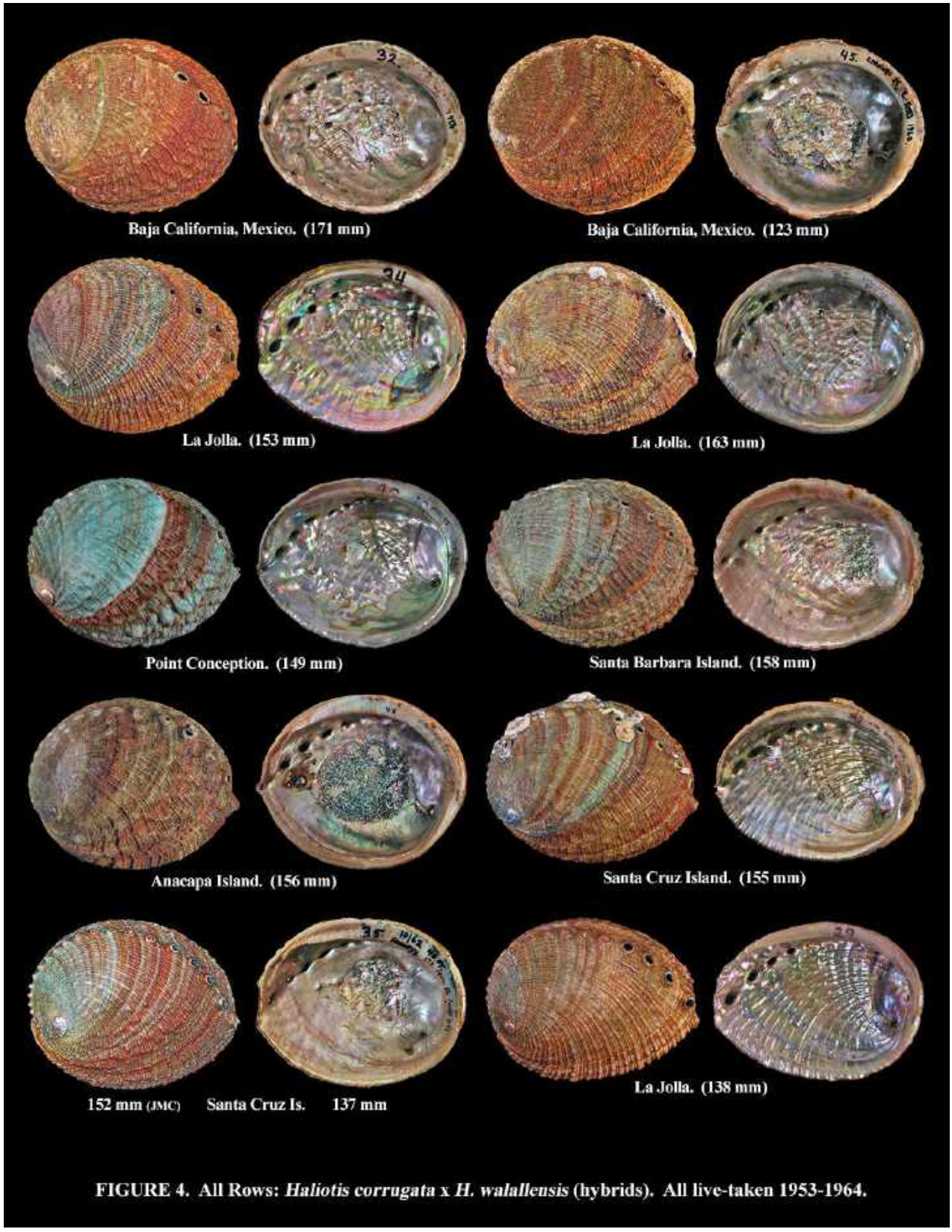

FIGURE 4. All Rows: *Haliotis corrugata* x *H. walallensis* (hybrids). All live-taken 1953-1964.

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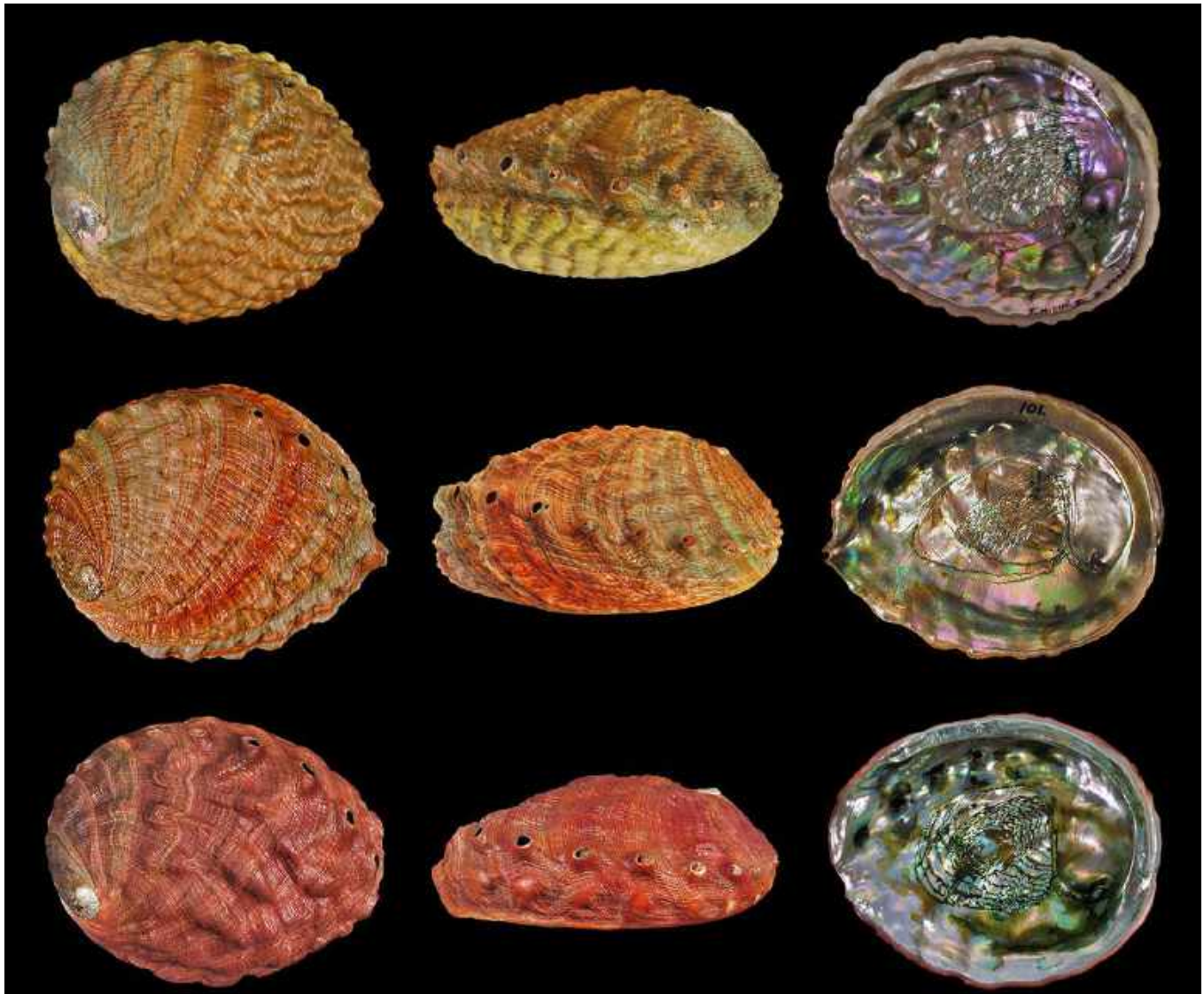

FIGURE 5. Top row: *Haliotis corrugata*. San Miguel Island. 155 mm. Center Row: *H. corrugata* x *H. rufescens*. San Nicolas Island. 152 mm. Bottom row: *H. rufescens*. San Miguel Island. 213 mm. All specimens live-taken by commercial abalone diving prior to 1965.

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FIGURE 6. All Rows: *Haliotis corrugata* x *H. rufescens* (hybrids). All live-taken 1953-1964.

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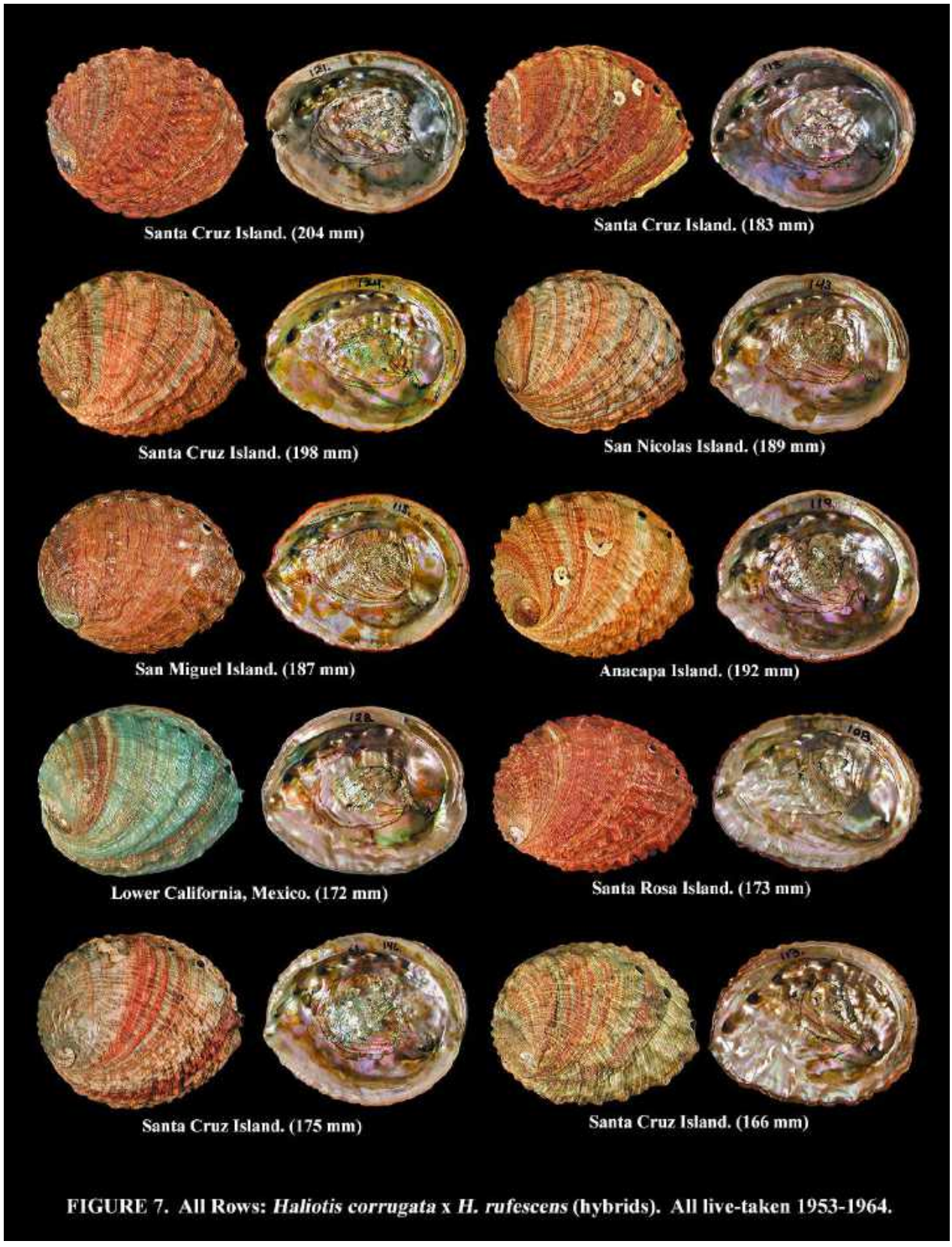

FIGURE 7. All Rows: *Haliotis corrugata* x *H. rufescens* (hybrids). All live-taken 1953-1964.

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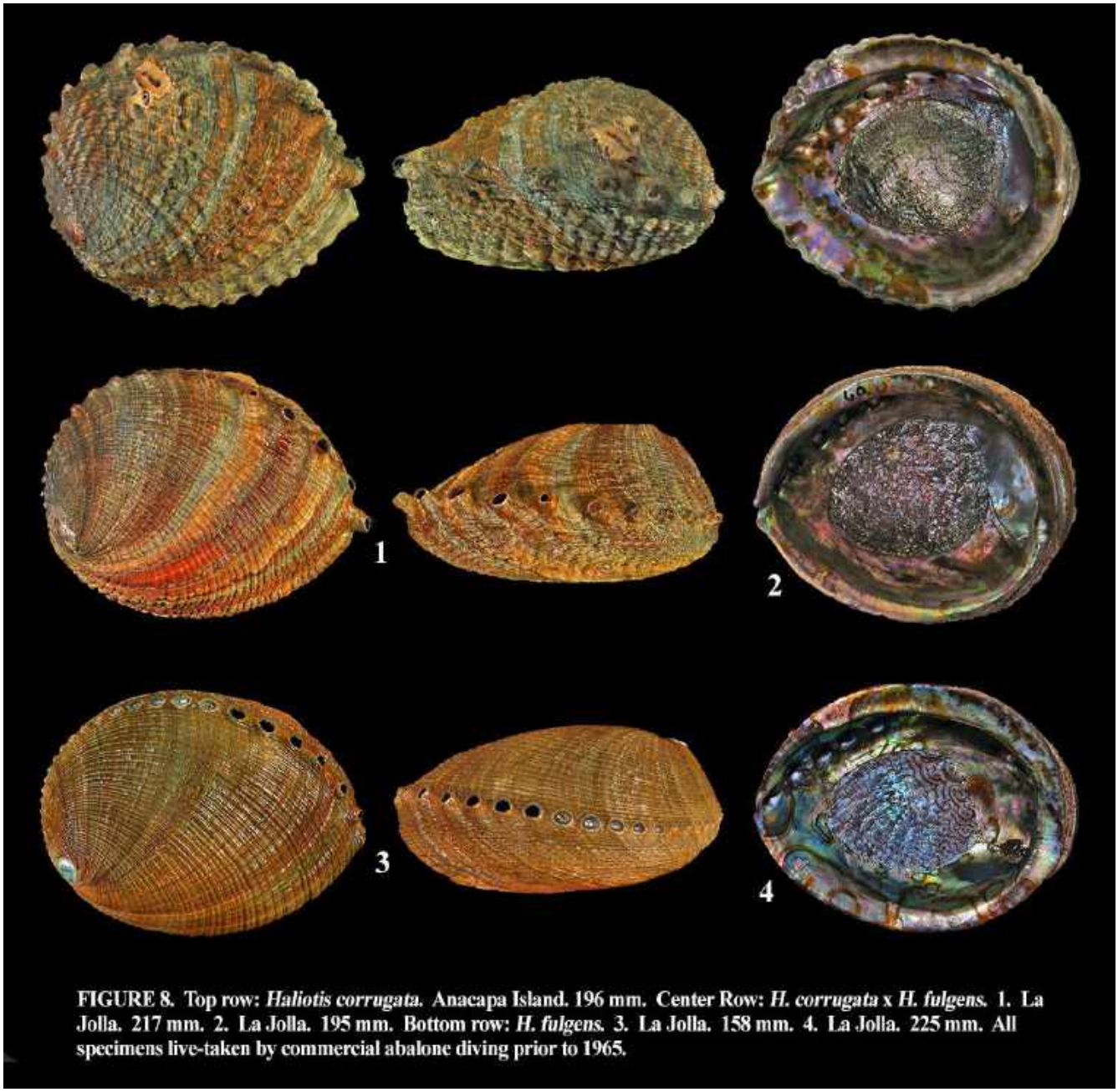

FIGURE 8. Top row: *Haliotis corrugata.* Anacapa Island. 196 mm. Center Row: *H. corrugata* x *H. fulgens.* 1. La Jolla. 217 mm. 2. La Jolla. 195 mm. Bottom row: *H. fulgens.* 3. La Jolla. 158 mm. 4. La Jolla. 225 mm. All specimens live-taken by commercial abalone diving prior to 1965.

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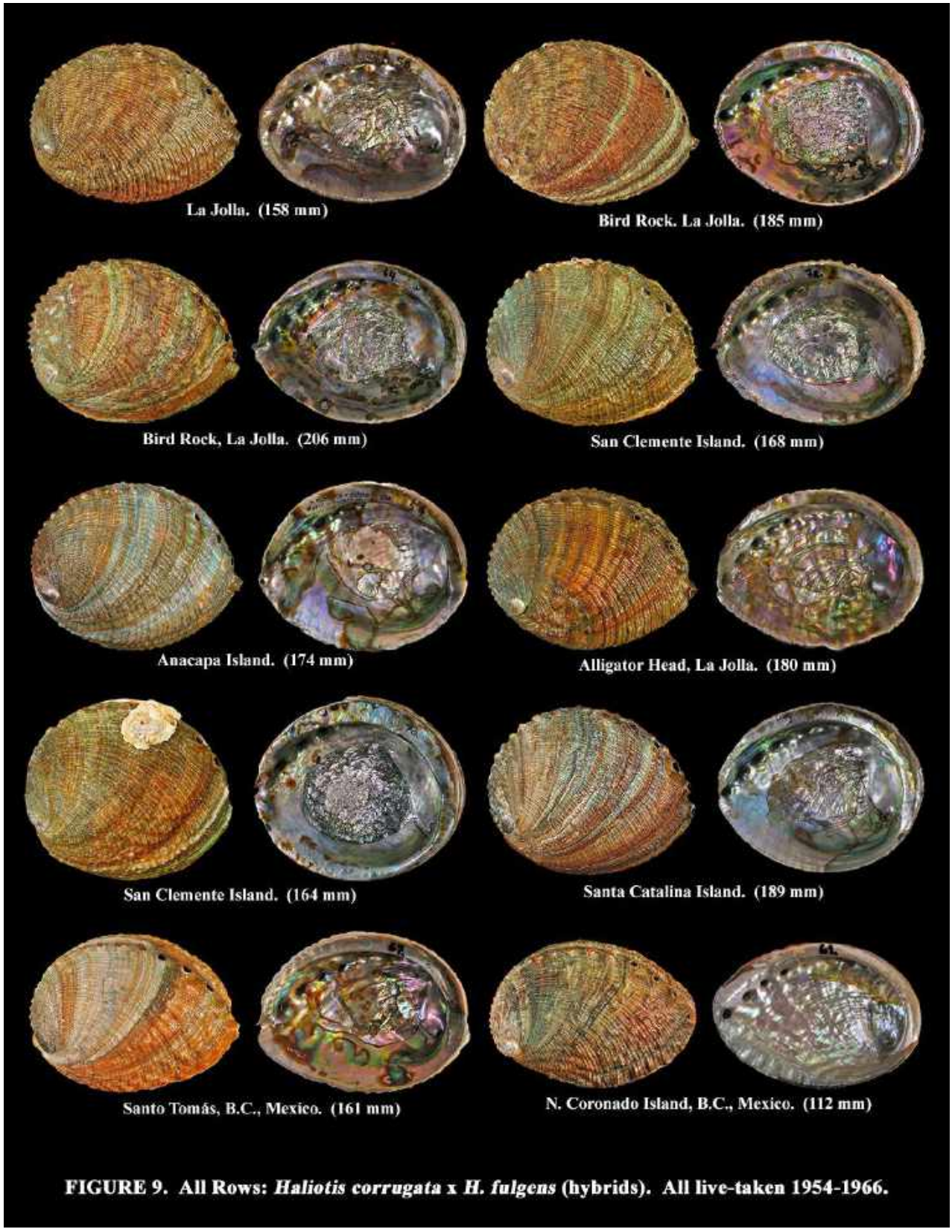

FIGURE 9. All Rows: *Haliotis corrugata* x *H. fulgens* (hybrids). All live-taken 1954-1966.

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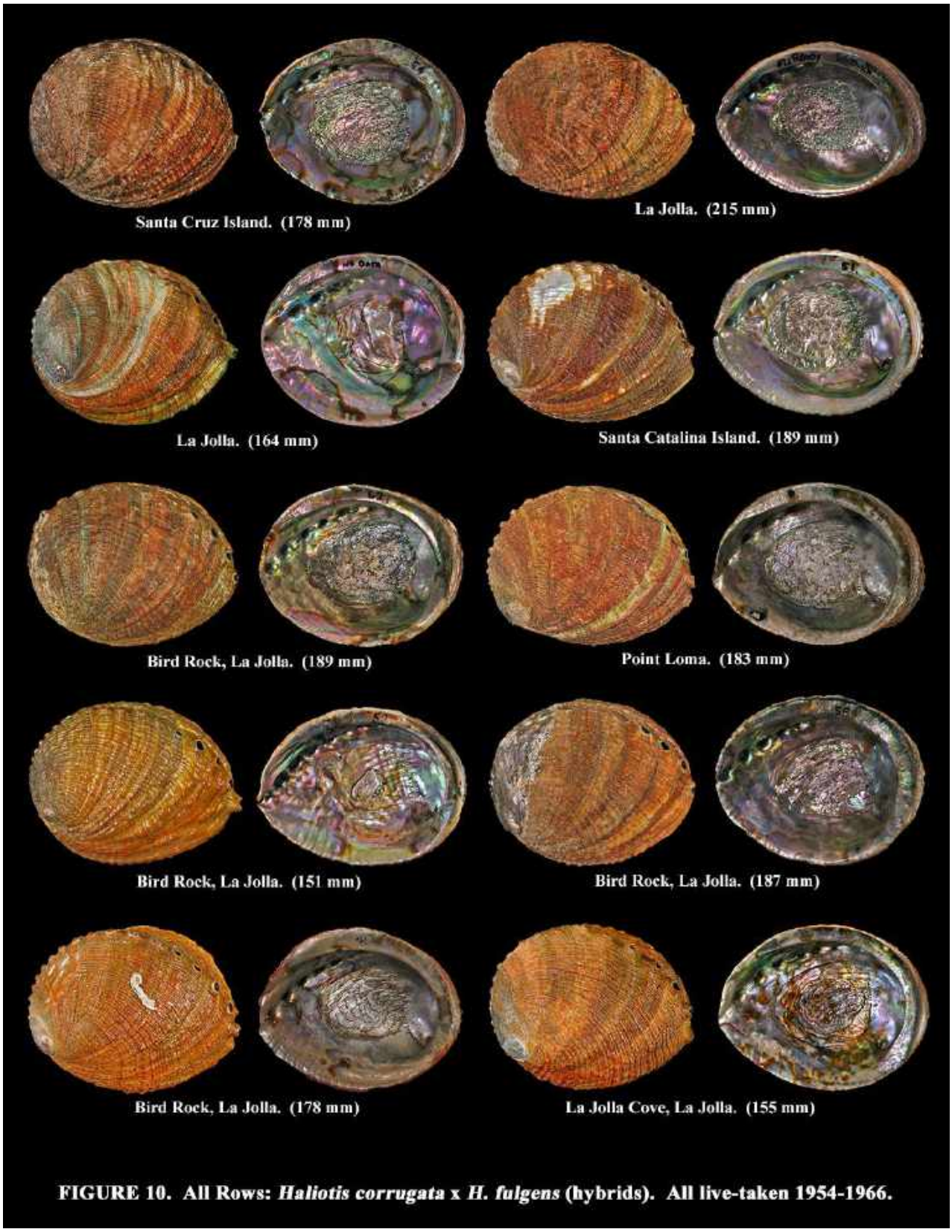

FIGURE 10. All Rows: *Haliotis corrugata* x *H. fulgens* (hybrids). All live-taken 1954-1966.

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FIGURE 11. Top row: *Haliotis corrugata*. San Miguel Island. 172 mm. Center Row: *H. corrugata* x *H. sorenseni*. San Clemente Island. 179 mm. Bottom row: *H. sorenseni*. Santa Cruz Island. 142 mm. All specimens live-taken by commercial abalone diving prior to 1968.

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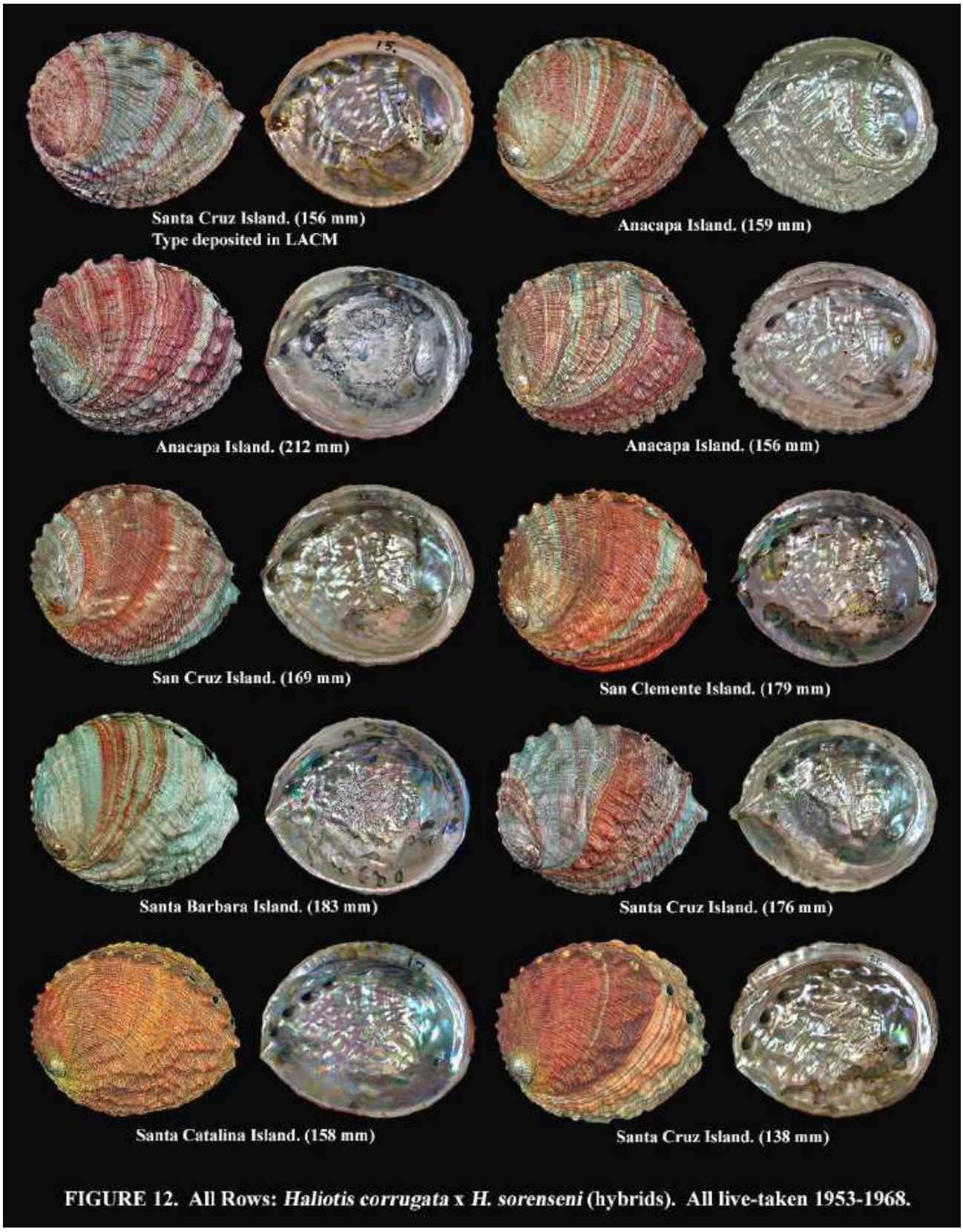

FIGURE 12. All Rows: *Haliotis corrugata* x *H. sorenseni* (hybrids). All live-taken 1953-1968.

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FIGURE 13. Row 1: *Haliotis corrugata*. Rows 2-4: *H. corrugata* x *H. kamtschatkana*. Row 5: *H. kamtschatkana*. All live-taken 1955-1970.

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FIGURE 14. Top row: *Haliotis corrugata*. Anacapa Island. 162 mm. Center Row: *H. corrugata* x *H. cracherodii*. Baja California, Mexico. 163 mm (DPC). Bottom row: *H. cracherodii*. Baja California, Mexico. 123 mm. All specimens live-taken prior to 1980.

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