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BIOLOGY AND FISHERY OF DOLPHINFISH AND RELATED SPECIES. *E. MASSUTÍ and B. MORALES-NIN (eds.)*

Seasonal abundance of the dolphinfish, *Coryphaena hippurus*, in Hawaii and the tropical Pacific Ocean*

SYD KRAUL

Pacific Planktonics. 73-998 Ahikawa St., Kailua-Kona, HI 96740-9407, USA. E-mail: kraul@konacoast.net

SUMMARY: This report looks at possible explanations for the seasonal abundance of the dolphinfish, *Coryphaena hippurus*, in Hawaii. In Hawaii and many parts of the Pacific Ocean, the abundance of *C. hippurus* (called mahimahi in Hawaii) varies seasonally in a pattern that is fairly consistent from year to year. Size frequency analysis shows that this pattern of seasonal landings matches the pattern of cohort abundance in certain years. The strongest cohorts are spawned in July, often stay in our fishing zone for at least 5 months, and may comprise the predominant portion of the catch through October. Even though mahimahi spawn copiously all year in captivity, the data here suggest that wild mahimahi either spawn less frequently, or their larvae survive better at certain times of the year. Thus, seasonal abundance of mahimahi in Hawaii might be a function of cohort survival. The abundance pattern also fits the pattern of change in seasonal surface temperatures, and it is quite possible that mahimahi migrate north and south to stay in the sea surface thermocline associated with the 23°C isotherm. Natural growth rates were derived from our size frequency analyses, and the rates matched growth rates reported in a previous study of otolith ring deposition. A significant increase in longline fishing in 1989 increased total landings but did not reduce the catch quantity or sales price for charter boat mahimahi.

Key words: growth rate, age, size frequency, temperature, migration, fishing methods, market price, flotsam.

INTRODUCTION

Economics

Commercial landings of mahimahi in Hawaii from 1987 through 1996 ranged from 150 metric tons(mt) to 600 mt per year. In Hawaii, mahimahi represent about 2-3% of the annual catch by weight, and less than 2% by value. Prior to 1989, more than 99% of this catch was landed by charter boats, using trolling gear within 50 miles of the islands. Many longline boats began fishing Hawaiian waters in 1989, and their mahimahi catch is now almost equal to the catch from trolling. Recent data from the State of Hawaii, Department of Land and Natural Resources, Division of Aquatic Resources, Statistics Program (DLNR) suggests a change in landing patterns due to the distance that longline boats travel. For the 30 years prior to 1989, spring landings were about twice the volume of the fall landings. The new fleet catches at least as many fish in the fall (especially November) as they do in the spring (Fig. 1).

The 1993 wholesale (auction) price for troll fish averaged US$5/kg, with a range of US$1 to US$20/kg. Longline fish sold for about US$3/kg: troll-caught mahimahi are normally chilled sooner

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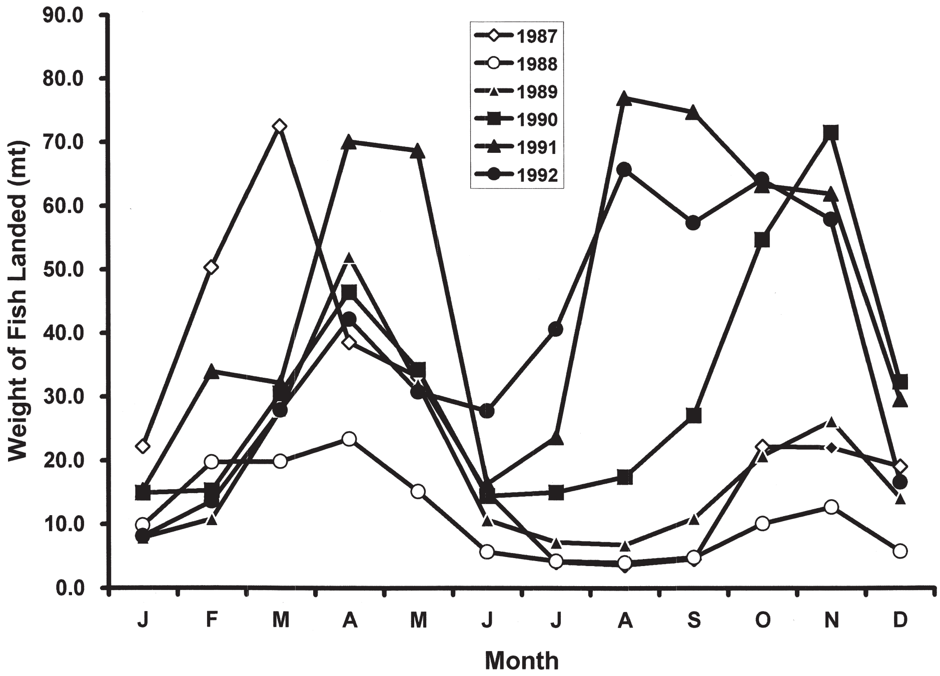

FIG. 1. – Monthly landing patterns of mahimahi in Hawaii for the years 1987 through 1992. From data supplied by the Hawaii DLNR, Division of Aquatic Resources Statistics Program.

than longline-caught fish, and Hawaii consumers pay more for fresher fish. Hawaii imports 75-90% of its mahimahi (mostly as frozen fillets) from nutrient-rich waters such as Equador, Costa Rica, and Taiwan, where fishermen receive as little as US$ 0.20/kg of whole fish.

Mahimahi enter the Hawaiian fishery when they are about 1.5 kg, but, due to customer preference and pricing, are not normally landed until they are at least 3 kg. The fish grow to 10 kg at one year, and are not frequently caught above 20 kg (about 1.5 years old) in Hawaii.

Biology

Mahimahi have a high metabolic rate (Benetti, *et al.*, 1995), and are highly oxygen dependent (captive fish show stress reactions when dissolved oxygen is less than 5.5 ppm, at 25°C). This keeps them near the surface, and catchable by Tahitian “poti marara” (a surface chase, followed by harpooning from a small powerboat), or Mediterranean surround net. Small juveniles are often found asssociated with drifting objects near Australia (Kingsford and DeFries, 1999) Spain (Riera *et al.,* 1999), Hawaii (our observations), and elsewhere. Adults can swim faster than 10 meters per second (even in our 6 m diameter tanks), and usually feed on pelagic species such as flying fishes and squids. They can feed at low light levels (i.e. moonlight), which would allow them to consume squid at night.

Mahimahi are widely distributed, and thought to migrate long distances in the western Atlantic and Mediterranean areas. Juvenile mahimahi about 2 cm to 6 cm are occasionally found under aggregations of small debris in Hawaiian waters. Newly mature mahimahi of about 1.5-2 kg are also found, often within two kilometers of Hawaiian shores. Aquaculturists seek these smaller fish as fresh genetic input to their breeding stock because they are easier to keep alive after capture.

Growth rate is very sensitive to temperature. Assuming a linear growth rate, aquacultured mahimahi grow 1.33 mm per day at 18°C, 3.22 mm per day at 25°C, and 5.74 mm per day at 29°C. These rates were derived from fork lengths of 72 cm at 18 months, 145 cm at 15 months, and 155 cm at 9 months for the cold, medium and warm temperatures respectively. These rates are estimates based on fish raised under similar feeding regimes (i.e. frozen squid and baitfish) in Hawaii and Australia. Hawaiian surface waters normally range from 23°C to 26°C throughout the year.

In captivity, female mahimahi spawn every two days throughout the year (Kraul, 1991). Newly mature females (1.5-2 kg) release about 30,000 eggs per spawn. Egg production increases to 400,000 eggs per spawn (10% of body weight released every two days) by the time the female is 4 kg (about 1 year old). Captive males weigh about 10 kg at one year. Growth differential between the sexes is much smaller for wild fish (Uchiyama *et al.*, 1986) than for captive fish. Wild females caught anywhere in our waters any time of year appear to be ripe at 1.4 kg or smaller, even though 95% of wild fish (Kraul, unpublished data) are considerably leaner than captive fish. We do not know if wild females spawn less frequently than captive females. The National Marine Fisheries Service (Uchiyama, personal communication) has looked extensively for larval mahimahi, but rarely found them in plankton tows.

We started this investigation of wild fish stock structure in 1986, to see if seasonal abundance would affect marketing of aquacultured mahimahi. Since that time, we have learned a great deal about mahimahi aquaculture, and profitable methods have been demonstrated on a pilot scale farm (Kraul, unpublished report). However, market unknowns still inhibit large scale investment. Hawaii catches less than 1,000 metric tons of mahimahi per year, so a big farm might have a big impact on prices. The 1991 introduction of a larger longline fishing fleet in Hawaii presented us with an opportunity to assess this impact, and this report is one attempt to make that assessment.

METHODS

Size frequency analysis for the years 1985-1987 came from fish auction records, and from measurements of weight and length at the Honolulu auction. United Fishing Agency (UFA), the auctioneer, records the weight (in pounds) of each fish sold, by boat. If a boat has several fish smaller than 5 kg, these fish are sometimes sold as a group, with the record showing number of fish and total weight of the group. Fish in these groups are about the same size.

Currently, individual fish weights are monitored at UFA twice a week by the National Marine Fisheries Service (NMFS) and the State of Hawaii Department of Land and Natural Resources, Department of Aquatic Resources (DAR). Each agency monitors one day per week. In the 1980s, almost every auction day (6 days per week) was monitored, primarily through the NMFS Market Monitoring project. DAR's Statistics program supplied most of the economics data presented here, and provided detailed breakdowns of landings by gear type, fish species, and monthly and yearly catch.

Much of the data for Hawaii and all of the South Pacific (except Tahiti) came from Don Kobayashi at the Honolulu Lab of the National Marine Fisheries Service. Kobayashi provided major input in analyzing possible mechanisms for mahimahi abundance patterns.

Tahiti data and analyses were provided by Arsene Stein at the Service de la Mer et de l'Aquaculture, Tahiti, French Polynesia.

RESULTS

The size frequency data for spring 1986 show strong modes in monthly catches (Fig. 2). The mode increases steadily from 2.3 kg in December 1985 to 8.2 kg in May 1986. At the same time, the number of fish in the mode (and the total catch) peaks in March, then declines through May. Note that the vertical axis in Figure 2 is in number of fish, rather than percent of fish. Plotting these mode sizes against time and converting weight to length yields a linear growth rate of 2.0 mm per day. This rate is identical to that reported by Uchiyama *et al.* (1986) for this size range, further confirming that validation paper. For the study of 1985-1987 individual auction weights, an age progression mode was only detectable for the January 1986 through May 1986 data. Years with no detectable cohort did not show greater or lesser seasonal abundances.

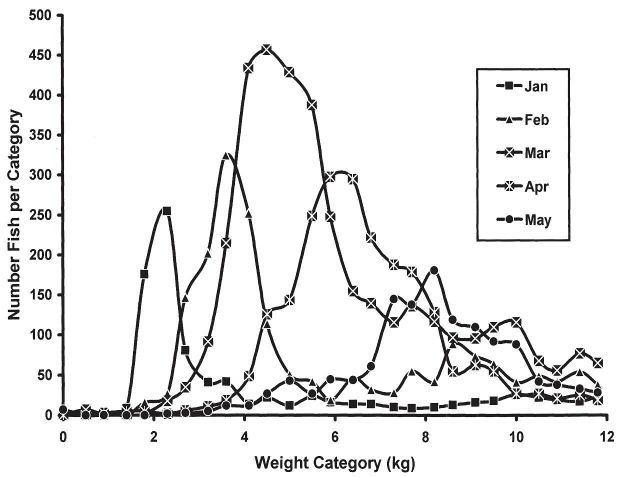

FIG. 2. – Cohort growth of Hawaiian mahimahi for January to May, 1986. Data was originally transcribed from auction records, in pounds, then sorted by size frequency. The irregular numbers on the X axis are a result of converting pounds to kilograms.

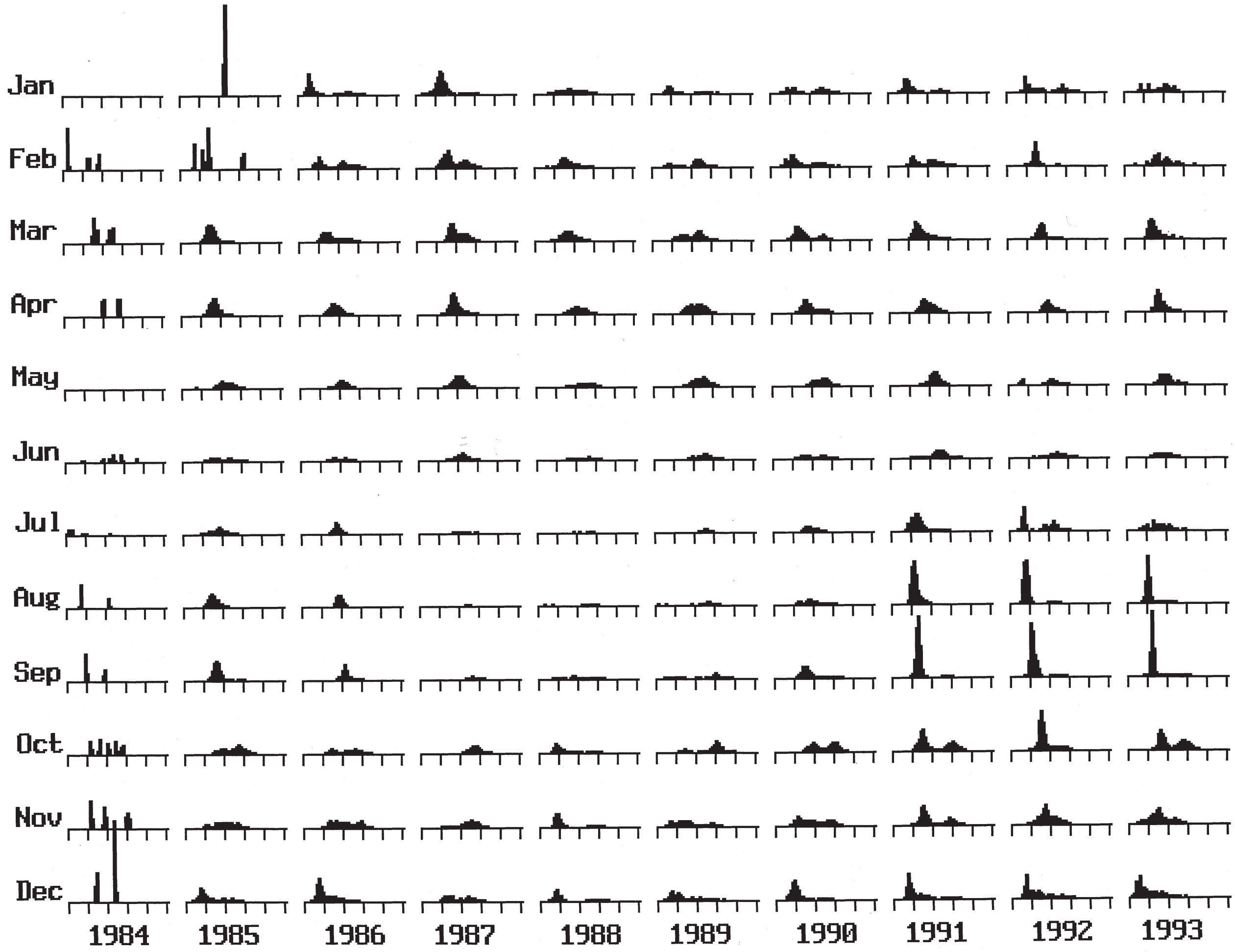

FIG. 3. – Size frequency of mahimahi *Coryphaena hippurus* in the main Hawaiian Islands, 1984-1993. From Kobayashi's analysis of longline fishing boat records from Honolulu auction, 1998.

Kobayashi's data from longline boat logs (Fig. 3) shows similar "cohort trends" for January through May of 1986, 1991, and 1992, and January through October of 1987 through 1989. From these data we can see that even before the 1991 increase in the long distance, longline fleet, yearly cohorts often stay within our fishery area.

Data provided by the DAR show the effect of increased effort on total catch and price of mahimahi. In 1987, the longline fleet was almost non-existent. Troll fishers reported catching 269 mt, while longliners reported 3 mt. These fish sold for about $5.50 per kg. In 1995, trollers caught 194 mt, while longliners caught 209 mt. Although the price for longline mahimahi is less than that for troll caught fish, trollers' prices did not drop. These "extra" fish are generally sold in a different market: troll fish go to fancy restaurants, longline fish go to supermarkets. Based on market studies to date, aquacultured fish would be expected to enter the fancy restaurant market (farmed fish are generally fatter and fresher than wild fish). However, pilot farm sales results show that supermarkets are willing to pay a premium price for dependability (they can plan their sales), and aquaculturists can thus obtain a fairly high price and larger sales volume at the same time, without hurting the local fisherman.

DISCUSSION

The bimodal abundance seen every year in Hawaii mahimahi landings could easily be accepted as a migration phenomenon. Oxenford and Hunte (1986), and Massutí and Morales-Nin (1995) have seen similar patterns in the Western Atlantic and Mediterranean respectively. Kobayashi tracked

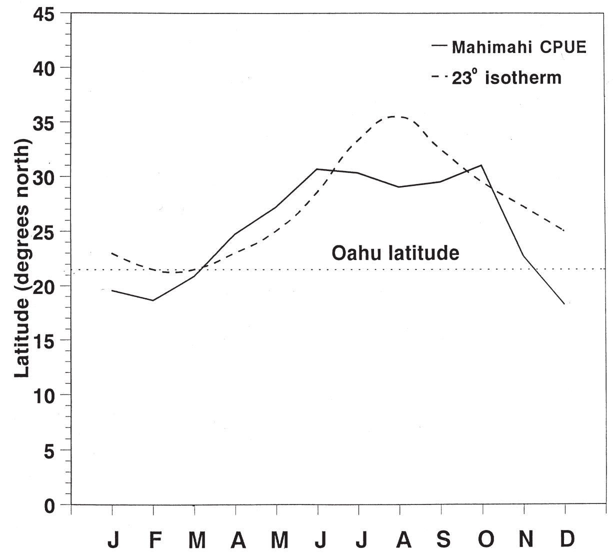

FIG. 4. – Monthly mean latitude of mahimahi longliner CPUE and 23°C sea surface temperature isotherm. The average latitude of longliner CPUE approaches the Hawaiian Islands twice a year in the same months the CPUE peaks in the near-island troll fishery. This apparent movement pattern closely mimics the monthly isotherm movement. From Kobayashi, 1997.

mahimahi CPUE (catch per unit effort, in weight per thousand hooks set) and sea surface isotherms by month and found that maximum CPUE moved north and south in greater correlation with the 23°C isotherm than it did for other isotherms(Fig. 4). Factors other than temperature are suggested, because the CPUE diverges from the 23°C isotherm at times. The migration hypothesis is also supported by the change in landings seen in Figure 1. If abundance is due to migration, then the change in abundance will be lessened as the longline fleet gets better at finding the fish.

Seasonal abundance might also be explained by propitious survival of larvae that are spawned in July. Maximum CPUE in July is near the 30° N latitude (Kobayashi, personal communication), where equatorial currents meet colder northern currents. At this latitude, there is a downwelling effect that concentrates drifting debris (Kubota, 1994). One to two month old (2-8 cm fork length) juvenile mahimahi are occasionally seen in Hawaiian waters, and are usually found associated with large aggregations of small pieces of floating debris. Their multicolored barred and blotched skin patterns at this size would camouflage them in this environment. The downwelling in this area probably concentrates food, as well as debris, by sweeping a broad horizontal area of buoyant or surface-seeking plankton into a narrow band.

Adult mahimahi can be caught on bait at 27-29°N latitude, in waters of about 18-19°C, and water this warm is occasionally present as far north as 40°N latitude (Uchiyama, personal communication). This combination of good feed and hiding places for larvae and adults could account for the strong cohort survival pattern seen in Hawaii landings. Young fish might then migrate south during winter, providing the largest peak (March) in landings. Although mahimahi spawn year round in captivity in Hawaii, our data suggest that either mahimahi spawn less frequently in the wild (supported by the smaller differential in male/female growth rates in the wild), or larvae survive better when they are spawned in warm water near floating debris. Survival of aquacultured larvae is best at 26-29°C.

Landing abundance patterns for some other Pacific islands are shown in Figures 5 and 6. Oceanographic data for these islands was not found by the author, but the figures suggest similarities between Samoa and Tahiti, and between Guam and the Northern Mariana Islands. Although Tahiti longline data resembles Samoa data in Figures 5 and 6, Tahitian harpoon fishery data (not shown) resembles Hawaii data, 6 months out of phase (our winter is their summer). Further interpretation is left to the reader. Landing quantities in Tahiti are about the same as in Hawaii. In 1996, the estimated catch was 62 tons by longline, 55 tons by trolling, and 140 tons by harpooning (Stein, personal communication).

It is quite possible that these patterns can be explained by large scale oceanographic phenomena, such as that presented by Norton (1999). The

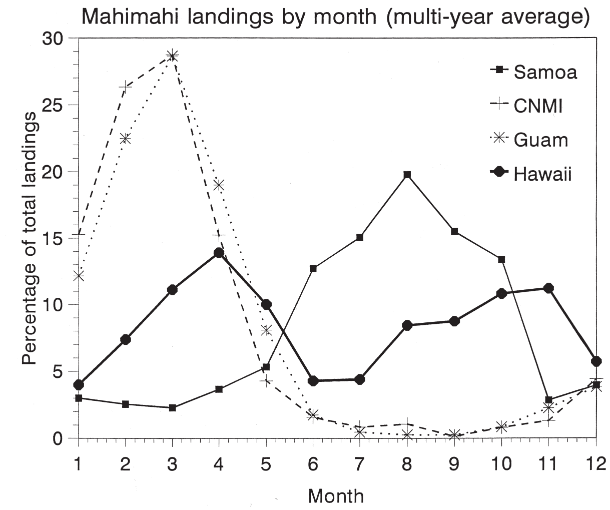

FIG. 5. – Mahimahi *Coryphaena hippurus* landings by month (multi-year average) in four tropical Pacific locations. From Kobayashi, 1997.

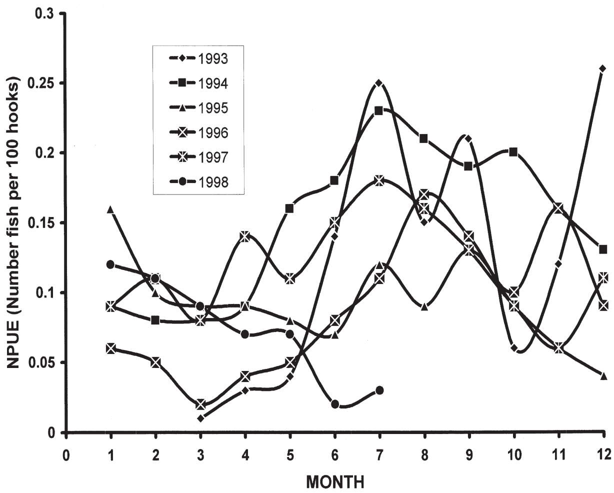

FIG. 6. – Number of mahimahi per unit (100 hooks) effort for the Tahitian longline fleet, 1993-1998. From Stein, 1997.

Hawaii data suggests a possible shift in the landings pattern after 1990. Prior to that time, charter boats caught most of their fish in the spring. The longline fleet has begun to catch as much in the fall as they do in the spring. They are able to stay in the area of higher CPUE as it moves north and south. These boats are targeting billfish, so the mechanism to explain mahimahi abundance may be a factor common to all fishes, like food abundance. It is interesting to see that the traditional disappearance of mahimahi during June and July still holds true. If this absence persists, a multi-cohort survival hypothesis would be strengthened. By June, "cohort- limited" mahimahi have probably reached old age, and there are few fish to catch until the next cohort reaches catchable size.

From this study, there appears to be a place in the market for more mahimahi, especially if it is marketed to certain niches. Landings in some years are dominated by cohorts that hatched in July of the previous season. The signature of these cohorts in size frequency analyses is strong enough to obtain a natural growth rate, and this growth rate matches the rate validated by the otolith increment method.

ACKNOWLEDGEMENTS

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Migration data for Hawaii and parts of the South Pacific came from Don Kobayashi at the Honolulu Lab of the National Marine Fisheries Service. Tahiti data came from Arsene Stein at the Service de la Mer et de l'Aquaculture. The Division of Aquatic Resources, Department of Land and Natural Resources, State of Hawaii provided extensive catch data and analysis that was used to reach some of the conclusions presented at this conference.

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