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The Indigenous Fisherman Divers of Thailand: Diving Practices

David Gold[a], Soomboon Aiyarak[b], Somchai Wongcharoenyong[c], Alan Geater[d], Wilawan Juengprasert[e] & Wayne A. Gerth[f]

[a] International Labour Office, Geneva, Switzerland
[b] Phuket Provincial Chief Medical Office, Phuket, Thailand
[c] Ranong Provincial Health Office, Ranong, Thailand
[d] Prince of Songkla University, Hatyai, Thailand
[e] Ministry of Public Health, Bangkok, Thailand
[f] Duke University Medical Center, Durham, NC, USA

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David Gold
International Labour Office, Geneva, Switzerland

Soomboon Aiyarak
Phuket Provincial Chief Medical Office, Phuket, Thailand

Somchai Wongcharoenyong
Ranong Provincial Health Office, Ranong, Thailand

Alan Geater
Prince of Songkla University, Hatyai, Thailand

Wilawan Juengprasert
Ministry of Public Health, Bangkok, Thailand

Wayne A. Gerth
Duke University Medical Center, Durham, NC, USA

Diving practices of a group of indigenous people living on Thailand's west coast were investigated. Village chiefs were first interviewed using a questionnaire. Three hundred and forty-two active divers were then interviewed by health care workers using a second questionnaire. Field observation was used to further develop information and confirm diving practices. Divers in 6 villages, whose basic means of making a living is from diving for marine products such as fish and shellfish, have diving patterns that put them at substantial risk of decompression illness. Breathing air from a primitive compressor through approximately 100 m of air hose, these divers have long bottom times coupled with short surface intervals. Forty-six point two percent of the divers indicated that they would not make a stop during ascent from a long deep dive (40 m for 30 min). When comparing their previous day of diving to the U.S. Navy Standard Air Decompression Table (U.S. Navy, 1993), 72.1% exceeded the no-decompression limits set by the tables. Diving patterns point to a need for more in-depth research into the diving patterns of this indigenous group. Future research should include the use of dive logging devices to record depths and times. There is also a need to provide divers with information and training to reinforce positive practices and strengthen knowledge of the risks associated with their current diving practices.

indigenous divers Thailand diving practices diving patterns

1. INTRODUCTION

In many parts of the world indigenous fishermen have turned to diving with compressed air as a way of harvesting various forms of marine life. Several professional groups have identified indigenous diving populations in South and Central America, Oceania, and Asia. For example, it has been suggested that there are as many as 33,000 indigenous divers in the Caribbean, Central America, and South America (B. Neitschmann, personal communication, May 3, 1996), and as many as 10,000 in the Philippines (M. Cross, personal communication, July 22, 1996). Thousands of indigenous divers are also thought to operate out of various coastal sites in Indonesia (M. Cross, personal communication, July 22, 1996), including the Sea Gypsies on the west coast of Thailand (Gold, 1998). Poor training by modern standards, primitive equipment, and use of decompression procedures that are either empirical or not designed for the conditions under which these divers operate cause these divers to experience high incidences of decompression sickness (DCS; Elliott & Moon, 1993; Melamed, Shupak, & Bitterman, 1992; Moon, Vann, & Bennett, 1995; Vann & Thalmann, 1993) and other

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Correspondence and requests for reprints should be sent to David Gold, Chemin des Cerfs, 1272 Genolier / VD, Switzerland. E-mail: <dgold@bluewin.ch>.

diving-related clinical disorders. Such problems have been described in indigenous divers in Australia (Edmonds, 1996; Ganter, 1994; Wong, 1996), the continental USA (Butler, 1995), Hawaii (Kizer, 1982; Wade, Hayashi, Cashman, & Beckman, 1978), Japan (Kawashima et al., 1995; Mohri et al., 1995), Mexico (Jones, Ramirez, & Doty, 1993), the island of Pescadores (Lee et al., 1994), the Philippines (Ball, 1993), the Republic of Korea (Park & Hong, 1991), Singapore (How & Long, 1995) and the Territory of Hong Kong (Lam, Yau, & O'Kelley, 1985). However, the practices and clinical consequences of diving by the Sea Gypsies of Thailand have been only cursorily studied.

The Sea Gypsies consist of three culturally distinct groups. One group, known as the Moken, are dispersed throughout the region from Phuket north to the border of Myanmar. Another group, known as the Urak Lawoi, live in villages from Phuket south to the Malaysian border (Hinshiranan, 1996). A third group, the Moklen, range from Phang-Na Province to Krabi Province and thus geographically overlap the other two groups. In some villages in Phuket and Krabi provinces, both Moken and Urak Lawoi live adjacent to each other and intermarry (Hinshiranan, 1996; Mayachiew, 1984). Both of these groups have a basic life style and have lived on or near the sea for many generations. The Moken, with the exception of a few villages on the island of Phuket, are breath-hold divers (Hinshiranan, 1996). Apart from a few of the Molken, the Urak Lawoi are the only people of the three groups already mentioned who use surface-supplied compressed air in their diving practice. The Urak Lawoi are consequently among the large group of indigenous divers world wide that may be at high risk for decompression sickness as a result of their diving practice.

The Urak Lawoi were once a nomadic people who, for the most part, are now settled permanently in villages (Hinshiranan, 1996). Almost all members of the younger generation have completed compulsory education in Thai schools and are literate. Virtually everyone speaks the Thai language. Most also speak their own language known as Passa Chaaw Lee (or Sea Gypsy Language), which is an unwritten Malay language (Hogan, 1972).

The Urak Lawoi have been foraging from the sea for many years. Their preferred food is fish (Engelhardt & Rogers, 1991), but their basic source of subsistence is shellfish, specifically oysters, which they can harvest when it is too difficult or dangerous to venture out to sea (Engelhardt & Rogers, 1993). As fish are a mobile resource, the Urak Lawoi have adapted their life styles to be able to gather fish and interact with other nomadic fishing groups they encounter. Urak Lawoi men spend 35% of their time and 85% of their working time fishing (Engelhardt & Rogers, 1991). The Urak Lawoi have traditionally used hook and line, traps, and spears to gather their catch. Approximately 30 years ago a group of these divers started using surface-supplied compressed air to extend the time and range of their underwater forays. This use of compressed air is viewed by the Urak Lawoi as an extension of traditional diving techniques. Today, approximately 400 indigenous divers on Thailand's west coast are using surface-supplied compressed air with its consequent risks of decompression sickness and barotrauma (Gold, 1998). A majority of these divers consider pain as a regular part of their work. Distrust of modern medicine and adherence to traditional beliefs causes Urak Lawoi divers suffering from decompression sickness to seek relief through traditional massage and balms rather than through treatment in a modern medical facility or hyperbaric chamber.

It had been reported in the local press that a considerable number of Urak Lawoi were using diving patterns that cause high incidences of decompression illness (Sakboon, 1996). In response to this concern, a project was developed by the principal author in collaboration with the Ministry of Public Health of Thailand to determine the safety and health risks faced by the indigenous divers of Thailand, and to develop interventions to either abate or reduce those risks. This paper is the first in a series to report results of this project. A paper addressing the divers' exposure to carbon monoxide gas in the breathing air is in press (Gold, Geater, Aiyarak, & Juengprasert, 1999). Other papers addressing mortality and morbidity (Gold, Geater, Aiyarak, Wongcharoenyong, Juengprasert, Johnson, & Skinner, in press), attitudes and awareness of hazards (Gold, Geater, Aiyarak, Wongcharoenyong, Juengpraesert, & Griffin, in press), and education and information as mechanisms for change (Gold, Geater, Aiyarak, Wongcharoenyong, Juengpraesert, & Chuchaisangrat, in press) follow this paper.

2. METHODS

2.1. Observation

From December 1995 to April 1997, the principal author made multiple trips to the west coast of Thailand to learn not only the diving practices but also the culture of the Urak Lawoi. The trips were timed to meet and observe the Urak Lawoi during both the wet and dry seasons. Discussions were held with village chiefs, dive leaders, boat owners, divers, and men who had been divers but were now disabled due to decompression illness. Consultations were also held with public health workers, nurses, and administrators within the local health care system. Diving practices were observed on several occasions. A field diary was kept and still photography was used to record both diving practices and village life.

2.2. Questionnaire Design, Piloting, and Implementation

Questionnaires were developed following a World Health Organization methodology on Health and Community Surveys (Lutz, Chalmers, Hepburn, & Lockerbie, 1992) to support a cross-sectional survey. Consultations were also held with three hyperbaric medical specialists and two epidemiologists. The first version of two questionnaires, Questionnaire No. 1 for the head of the village and Questionnaire No. 2 for active divers, was drafted in English and translated into the Thai language, which is spoken, read, and written by virtually all of the Urak Lawoi divers.

Both questionnaires contained closed questions, open questions, and questions that were both closed and open. A closed question is a question designed to allow the interviewer to select only from a list of given responses. An open question is designed to allow the interviewer to record a response as there are no given responses to check. A question that is both open and closed provides responses for the interviewer to check but also allows for the recording of a response should the list of given responses not fit the answer to the question (Lutz et al., 1992). Questionnaire No. 1 was designed to gather demographic data and information about access to medical care from the heads of villages. Questionnaire No. 2 was designed to acquire information from the divers about their diving practices, awareness of associated risks, and attitudes towards those risks.

The head of village and one diver in Rawai were interviewed in a pilot survey conducted by one public health specialist and one occupational physician using the first version of the questionnaires. The principal author and members of the project team were present as observers. Results of this pilot were used to refine the questionnaires in October 1996. An implementation team of 14 public health officials from provinces known to have indigenous divers (Phuket, Krabi, and Satun) was then selected by the Ministry of Public Health and trained in the survey methodology. The questionnaires were revised into final form based on feedback obtained during team training. The team then went into each village and conducted an interview with the village leader using Questionnaire No. 1 and with each diver using Questionnaire No. 2. Every effort was made to interview each active diver in each village. The health care worker posed the questions and then recorded the responses. All interviews were conducted in the Thai language. (The native language of the Urak Lawoi, Passa Chaaw Lee, is an unwritten language that most of the health care workers do not speak.) Interviews were randomly monitored by either the principal author or other members of the project team. The data from Questionnaire No. 1 was manually extracted for analysis. The data from Questionnaire No. 2 was entered onto a computer for analysis using Epi Info Version 6 software (Dean et al., 1995).

2.3. DCS Risk Assessment

The divers keep no dive logs and could not provide reliable recollections of multiple days of diving. One section of Questionnaire No. 2 required the divers to provide depths, bottom times, and surface intervals for the first five dives during their last day of diving before interview. (Although some of the divers made more than five dives, only the first five dives were taken into consideration). This last day of diving was then considered representative of their daily diving practice. The first 302 profiles were examined for conformance to the U.S. Navy Standard Air Decompression Table (U.S. Navy, 1993). As the completed questionnaires allowed, profile summaries were also encoded for analysis using a probabilistic model (Gerth & Vann, 1996, 1997). The latter analyses provided quantitative estimates of the cumulative probabilities of DCS for each profile. Profile summaries were encoded under the following rules and assumptions:

1. Air breathing throughout;
2. Surface pressure = 101.3250 kPa (1 atm), sea-level;
3. 20 m/min ascent and descent rates;
4. Bottom time at each recorded DEPTH computed as the recorded TIME entry minus the corresponding descent time. The latter was calculated from the assumed descent rate and the recorded DEPTH.

The model (Gerth & Vann, 1996; Thalmann, Parker, Survanshi, & Weathersby 1997) had been calibrated to the U.S. Navy Naval Medical Research Institute BIG292 data set of air and N2-O2 dives as described in

Reference 34. This is the same data used to develop the USN93 Air/Nitrox Decompression Algorithm (Thalmann et al., 1997).

3. RESULTS

3.1. Field Observation: Equipment

The Urak Lawoi dive from open boats that are from 7 to 11 m in length (Figure 1). The boats are powered by a traditional "long tail," which consists of a large gasoline engine mounted on a stern swivel. The propeller is mounted on a long rigid shaft extending from the motor. The boat is manoeuvred by moving the motor on its swivel.

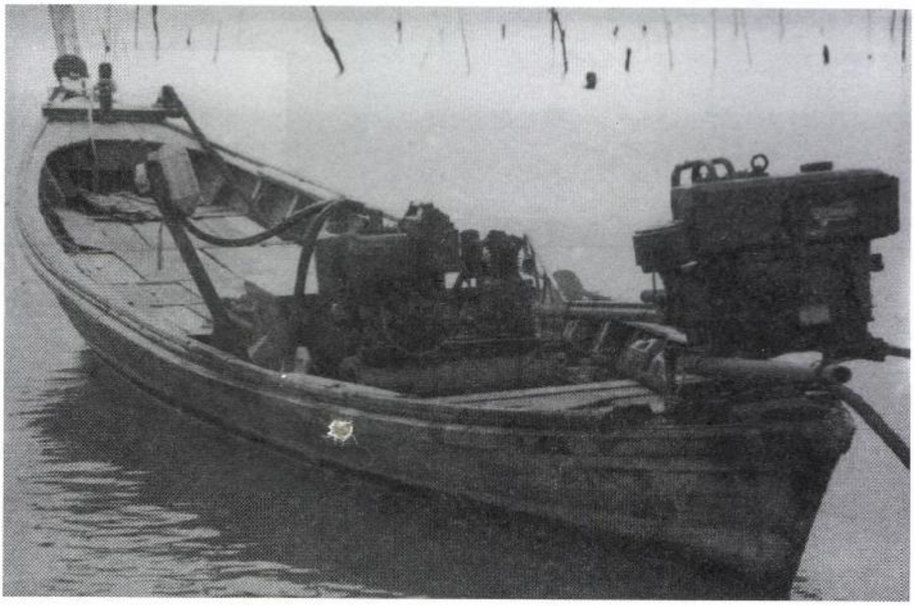

Figure 1. The traditional dive boat with the compressor located in the middle of the boat.

Air is supplied to the diver from a primitive compressor (Figure 2), which is powered by either a gasoline or diesel engine. The unfiltered compressed air is passed into a pressure tank and down approximately 100 m of plastic hose to the diver. There, the hose is attached to a tire valve fitted to the skirt of a standard diving mask just above the right eye (Figure 3). A small piece of neoprene covers the valve penetration in the interior of the mask to act as both a deflector and one-way valve. Inspiration and expiration are effected through the nose, the expired air escaping from the skirt of the mask. As there normally is a distance of less

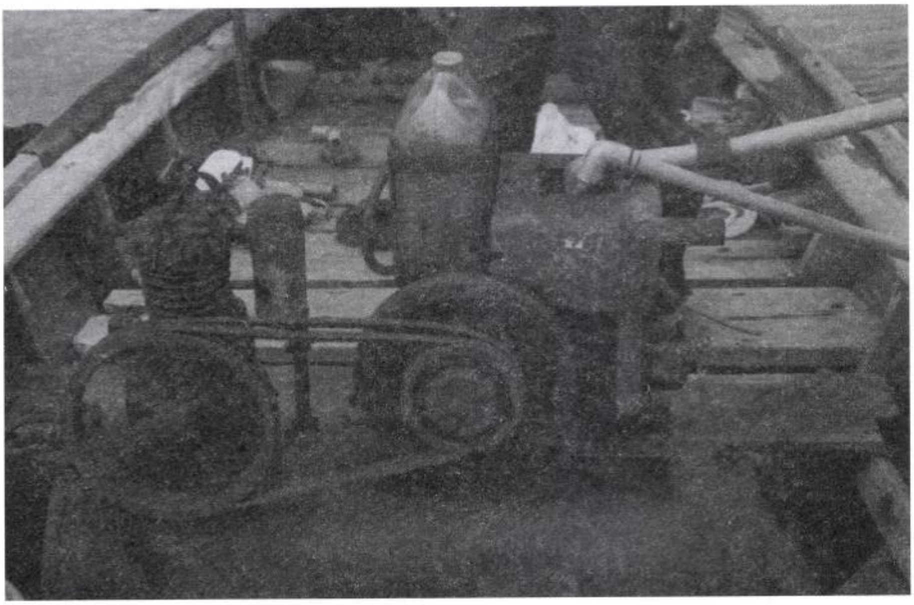

Figure 2. A crude truck compressor pumps air to the working divers.

Figure 3. Air is supplied through a modified diving mask.

than 100 cm between the compressor motor exhaust and the air intake for the compressor, there is a risk of carbon monoxide poisoning (Gorman, 1993) and illness from exposure to diesel emissions (Boffetta, Saracci, Kogevinas, Wilbourn, & Vainio, 1998), especially when the air intake is downwind of the exhaust.

Diver dress consists of a long sleeved shirt with a roll collar, a pair of plastic or rubber shoes, and a pair of athletic style trousers (Figure 4). Hand protection is provided by a pair of cotton mesh gloves. A weight belt may be worn to control buoyancy. Descents are sometimes facilitated by carrying a rock, which is readily jettisoned upon reaching the intended dive depth.

Figure 4. Urak Lawoi diver harvesting fish from a coral reef.

3.2. Questionnaire No. 1

Eleven heads of village were interviewed using Questionnaire No. 1.

3.2.1. Villages

The Urak Lawoi and their families currently inhabit 9 villages. Six of these villages, some of which are actually geographic clusters of several small villages, have active divers (Figure 5). Through Questionnaire No. 1, it was determined that, within the 9 villages, 1,106 families are permanent residents and 27 families are nomadic. Reported sources of income within the 6 villages were fishing (6 villages), labour (3 villages), commerce (1 village), and construction (1 village, Table 1).

TABLE 1. Summary of Information by Village

Province	Name of Village	Estimated Population	Number Divers Interviewed	Means of Income	Number of Years Divers Have Been Diving With Compressor	Target Catch	Number of Boats With Compressors
Phuket	Rawai	1,900	98	fishing, labor, commerce	33	fish, prawn, shell fish, crab, squid	30
	Koh Siray	1,524	85	fishing, labor	17	fish, prawn, shell fish, crab, squid	25
	Sapam	252	18	fishing, labor, construction	25	fish, shell fish, salvage	2
Krabi	Koh Lanta	996	49	fishing, labor	20	shell fish, lobsters, squid, pearls	4
Satun	Koh Boulon	380	18	fishing	6	fish, shell fish, crabs, lobster	6
	Koh Li Peh	820	66	fishing, labor		shell fish, lobster	20

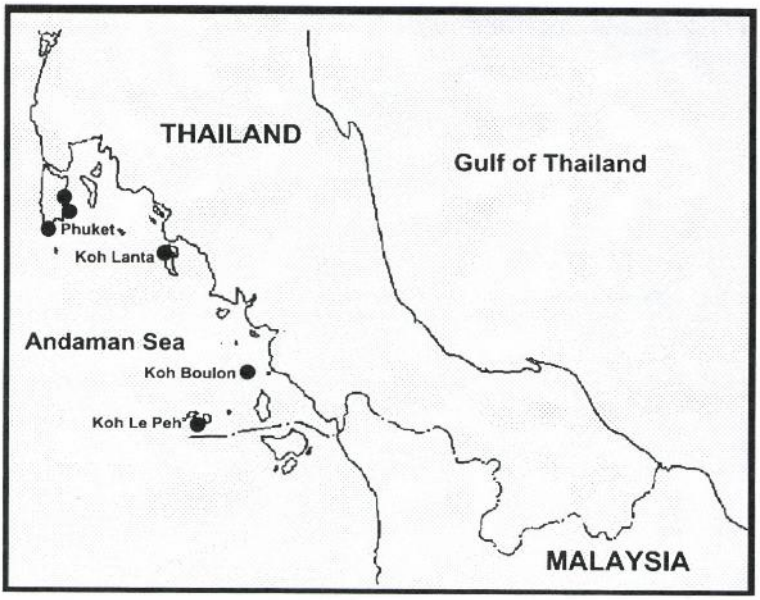

Figure 5. Locations of principal Urak Lawoi villages with active divers.

3.2.2. Medical care

Three villages have residents trained in first aid. In Phuket, Koh Siray, Rawai, and Lee Peh have 21, 10, and 4 village health care volunteers, respectively. A health care centre staffed with medically trained personnel (physicians, nurses, or both) is in close proximity to most villages. Travel time to the nearest centre is 5–10 min from most villages, but can be as high as 1 1/2 hrs from some villages. With the exception of Koh Lee Peh, the time to gain access to a physician ranges between 10 min to 3 hr. Koh Lee Peh reports that a physician can be seen only after 10 hrs of travel by sea. Three of the 6 villages have oxygen available.

There is one private recompression chamber located in Phuket. The chamber was established in December 1995 and to date has treated 8 indigenous divers from the village of Rawai.

3.2.3. Diving operations

The dive unit is the dive boat. There are 87 boats currently in use with compressors (Table 1). The target catch varies and includes fish, lobster, shellfish for food, seashells for the tourist industry, squid, and prawns (see Table 1). Several villages also engage in salvage operations. Dive sites are chosen by the boat owner (1 village), the divers (2 villages), the dive team leader (1 village), and a combination of boat owner and divers (2 villages).

Different formulae are used in different villages to allocate the profits of a dive operation. In 5 villages for which such information was obtained, profits are allocated 50% owner/50% divers (1 village), 60% owner/40% divers (1 village), 66.6% owner/33.3% divers (2 villages), and 70% owner/30% divers (1 village). In a sixth village, the profits are divided into shares. Each diver, the boat owner, the engine owner, the compressor owner, and the boat captain receive 1 share. The chief of the boat receives 1 1/2 shares, and the boat owner receives an additional share if he accompanied the boat on the dive trip. It was also learned that if a diver from this village dies while at work, the owner shares a portion of his or her future shares with the widow and family until the widow remarries.

3.3. Questionnaire No. 2

Three hundred and forty-two active divers were interviewed using Questionnaire No. 2.

3.3.1. Diver profile

Only males dive. The divers interviewed ranged in age between 13 and 62 years with a median age of 29 years (Table 2). They started diving at a young median age of 17 years. Eighty-seven point three percent (295/338) stated that they started diving before the age of 20. Four of these individuals claimed to have started diving at only 8 years of age. The oldest age at which any respondent claimed to have started diving was 55 years. Thirty-one point one percent (105/338) of the divers had 0–9 years of breath-hold diving experience before first using compressed air, 45.9% (155/338) had 10–19 years of such experience and 23.1% (78/338) had over 20 years' experience.

TABLE 2. Divers by Age Group

Age (years)	Divers (%)
10–19	38 (11.1)
20–29	138 (40.3)
30–39	113 (33.0)
40–49	45 (13.2)
50–59	6 (1.8)
60–69	2 (0.6)

Notes. $n = 342$. Figures have been normalized to 100%.

3.3.2. Diving practices: diving patterns

Diving patterns vary amongst the villages. Distances to dive sites, depths of dives, bottom times, the frequency of dives, and the time on the surface between dives also vary depending on the target catch, the season of the year, the phase of the moon, and the weather. The year is split into two seasons, the wet season from mid-April to mid-October, and the dry season from mid-October to mid-April. Normally the sea is calmer during the dry season and the divers are more active, averaging 16.5 dive days per month. In contrast, activity is limited to an average of only 11.8 dive days per month during the wet season. The average number of dives per day during either season is about the same (dry season, 5.3; wet season, 4.7).

Diving is organised by the boat owner, the boat captain, and the divers. The boat may leave early in the morning and come back in the evening or it may leave for several days. Depending on where the divers are working, a long distance away from their home village may also translate into a long distance from medical care. The mean of 331 diver responses to a query about their longest time away from home while diving was 7.3 days and the median was 7.0 days. Thirty-nine point nine percent (132/331) reported that their longest dive trip was between 7 and 15 days in length, and 10.3% (34/331) reported 15 days or more. The maximum time away from home was 30 days.

3.3.3. Diving practices: dive depth and bottom time

Divers need to know their depth and the amount of time they remain underwater. Divers in the various villages could report the depths of their

TABLE 3. Measurement of Depth and Time Under Water

Variable	Method of Measurement	Divers (%)
Depth	Guessed or not measured	66 (19.3)
	Anchor line or other line	212 (62.0)
	Air supply hose	11 (3.2)
	Estimated by arm length	44 (12.9)
	Other	9 (2.6)
Time	Guessed or not measured	166 (48.5)
	A watch used while diving	125 (36.6)
	Kept on the boat and signalled	26 (7.6)
	Feeling tired, cold, or experiencing pain	21 (6.1)
	Other	4 (1.2)

Notes. $n = 342$.

dives with relative confidence. Depths were usually known because the divers frequented certain dive locations and knew the tides. They would also know how much of the anchor line was laid out at a site before the dive. This was confirmed by the questionnaire (Table 3). When asked to recall the deepest dive in their diving careers, most of the divers interviewed, or 85.9% (292/340), claimed not to have dived below 59 m (Table 4).

TABLE 4. Deepest Dive Recalled in Career

Deepest Dive (m)	Divers (%)
0–19	15 (4.4)
20–39	82 (24.1)
40–59	195 (57.4)
60–79	43 (12.6)
80–99	5 (1.5)

Notes. $n = 340$. Figures have been normalized to 100%.

The measurement of time while diving is as important as dive depth. Divers use a variety of means to track their dive times (Table 3) and were generally less aware of these times than their dive depths. Some divers stated that they occasionally dived until tired or cold.

3.3.4. Diving practices: 10-year trend in dive depths and bottom times

The divers were asked whether, over the past 10 years (or since they started diving), their diving times had stayed the same, increased, or decreased. Thirty-two point two percent (109/339) responded that the average bottom time per dive had remained unchanged, 29.5% (100/339) felt that the bottom time had increased, and 38.3% (130/339) felt that the time had decreased. When asked a similar question about their average dive depth, 24.8% (84/339) felt that the average depth had remained unchanged, 30.1% (102/339) felt that the depth had increased, and 45.1% (153/339) felt that the depth had decreased.

3.3.5. Diving practices: ascent rates

The rate of ascent from a dive may be a factor governing risk of decompression sickness. Current practice in commercial, military, and recreational diving is to ascend no faster than 18 m/min (Egstrom, 1993).

More practically, divers are taught that they should never ascend faster than the bubbles from their exhaled air. Urak Lawoi divers were asked to characterise their usual ascent rates based not on numerical figures, but relative to the speed of their ascending bubbles. Seventy-eight point seven percent (266/338) of the respondents indicated that they surfaced slower than their bubbles, 9.2% (31/338) indicated that they surfaced at the same speed as their bubbles, and 12.1% (41/338) responded that they surfaced at a rate faster than their bubbles.

3.3.6. Diving practices: decompression stops

Divers were asked if they made any decompression stops on 30-min or longer dives to depths deeper than 40 m. The U.S. Navy Standard Air Decompression Table (U.S. Navy, 1993), for example, prescribes 5- and 21-min stops at 6 and 3 m, respectively, before surfacing from a 40-m, 30-min dive. Forty-six point two percent (147/318) of the respondents indicated that they would not make a stop, whereas 53.8% (171/318) indicated that they would make one or more stops on such dives.

3.3.7. Diving practices: yo-yo diving

Yo-yo dives are a series of short dives separated by short surface intervals, undertaken to retrieve a series of traps or to bring successive catches to the boat while working a given underwater harvest site. The divers were asked if they engaged in yo-yo diving, defined as making successive dives that are each of less than 5-min bottom time. Nearly half of the respondents, 48.8% (164/336), stated that they did not engage in yo-yo diving. The remaining

TABLE 5. Incidence of Yo-Yo Diving

	Number of Dives (per day)				
Depth (m)	< 5	5–9	10–19	≥ 20	Total
0–9	39	23	10	2	74
10–19	34	26	6	3	69
20–29	6	8	3	0	17
30–39	1	3	0	0	4
40–49	2	0	0	0	2
50–59	1	0	0	0	1
Total	83	60	19	5	167

Notes. $n = 167$.

divers that claimed to yo-yo dive were asked to indicate their average number of dives per day and their average dive depth. Fourteen percent (24/172) of these individuals claimed to dive 10 or more dives per working day (Table 5).

A 16-year-old diver in one village reported that he had done 20 dives to depths less than 10 m on his last day of diving. Since he has been diving, he has suffered three incidences of decompression sickness.

The deepest depth averaged by a yo-yo diver was 50 m. This 39-year-old dived fewer than 5 times per day. He indicated that he experiences joint pain after every dive, commencing within 1 hr after surfacing and usually persisting for 2 hrs. He also experiences tingling and loss of sensation in both upper and lower extremities.

3.3.8. Diving practices: depths, bottom times, and estimated DCS risks on the last day of diving

The divers were asked about their last day of diving. Eighty-five point six percent (274/320) indicated that they had made between one and five dives (Table 6). The maximum dive depth reported by any of the divers was 80 m with a bottom time of 60 min, reported by a 45-year-old diver. The longest bottom time was 4.5 hrs at 44 m.

TABLE 6. Dives During the Last Day of Diving

Number of Dives	Divers (%)
1	24 (7.5)
2	72 (22.4)
3	80 (24.8)
4	58 (18.0)
5	40 (12.4)
6–10	35 (10.9)
11–30	13 (4.0)

Notes. mode: 3.0, mean: 4.2, $n = 322$.

3.3.9. Diving practices: estimated DCS risks

A majority of the divers, or 73.1% (201/275), exceeded the no-stop limits of the U.S. Navy Standard Air Tables (U.S. Navy, 1993) during at least one of the dives on their reported last day of diving. A large fraction of these individuals, or 64.7% (130/201), exceeded the limits on the first dive of that day (Table 7).

TABLE 7. Diving Profiles in Relation to U.S. Navy No-Decompression Limits for Single and Repetitive Air Dives (U.S. Navy, 1993)

Diving Profile	Divers (%)
Profile within the no-decompression limits	74 (26.9)
Fourth dive exceeds the no-decompression limits	2 (0.7)
Third dive exceeds the no-decompression limits	13 (4.7)
Second dive exceeds the no-decompression limits	56 (20.4)
First dive exceeds the no-decompression limits	130 (47.3)

Notes. $n = 275$.

Three hundred and eight "last-day" dive profiles were successfully constructed from information obtained in Questionnaire 2 for analysis using the BVM(3) probabilistic model. Results were used to group profiles into low (0.0–2.5%), moderate (2.5–10.0%), and high (> 10.0%) DCS risk categories. These risk ranges are put into perspective by comparison to estimated risks of schedules that are accepted as safe in modern diving practice. For example, only 10% of the U.S. Navy Standard Air Decompression Tables incur estimated DCS risks greater than 10% under this model (Gerth & Vann, 1996). Similarly, the mean estimated DCS risk of the U.S. Navy no-decompression limits for single dives (U.S. Navy, 1993) is 2.2%.

Table 8 shows the number of profiles in each DCS risk category overall. More than 23% of the divers undertook high risk profiles during their last diving day before interview. Thus, considering dive depth and time alone with reasonably assumed ascent rates, the practices of these divers incurred DCS risks higher than those associated with all but a few of the decompression dive schedules in the U.S. Navy Standard Air Decompression Table (U.S. Navy, 1993). Another 35% of the divers undertook moderate risk profiles on their last diving day before interview. A majority of the last-day profiles therefore incurred DCS risks higher than the mean DCS risk of the U.S. Navy no-decompression limits for single air dives.

Table 8 also shows the number of profiles in each DCS risk category as further broken down by village and age group. Divers from the villages of Koh Serai, Koh Lanta, and Rawai tended to dive profiles with the highest estimated DCS risks. More than 25% of the divers from these villages dived

TABLE 8. Estimated DCS Risks for Last-Day Dive Profiles

Variable	Profiles Analyzed	Profiles in Category (% in group)		
		Low Risk	Moderate Risk	High Risk
Age				
13–19	35	20 (57.2)	9 (25.7)	6 (17.1)
20–29	126	47 (37.3)	47 (37.3)	32 (25.4)
30–39	99	31 (31.3)	40 (40.4)	28 (28.3)
40–49	41	27 (65.9)	8 (19.5)	6 (14.6)
50–62	7	1 (14.3)	5 (71.4)	1 (14.3)
Totals	308	126 (40.9)	109 (35.4)	73 (23.7)
Village				
Rawai	84	27 (32.1)	33 (39.3)	24 (28.6)
Koh Serai	83	11 (13.3)	45 (54.2)	27 (32.5)
Sampam	8	6 (75.0)	1 (12.5)	1 (12.5)
Koh Lanta	45	19 (42.2)	12 (26.7)	14 (31.1)
Koh Bulon	17	11 (64.7)	5 (29.4)	1 (5.9)
Koh Le Peh	64	49 (76.6)	11 (17.2)	4 (6.3)
Totals	301	123 (40.9)	107 (35.5)	71 (23.6)

Notes. DCS—decompression sickness, $n = 308$. Figures have been normalized to 100%.

high risk profiles on their last diving day before interview. In comparison, fewer than 15% of the divers from the other villages dived high risk profiles on their last diving day. Similarly, more than 25% of the divers from these villages dived moderate risk profiles on their last diving day.

As might be expected, the waxing and waning of familial responsibilities with age appears to govern which divers undertake the higher risk profiles. A large majority, or 65.3% (147/225), of the dives undertaken by the intermediate 20–39-year-old divers had DCS risks within the moderate or high ranges. In comparison, only 42.9% (15/35) of the younger divers aged 13–19, and 41.6% (20/48) of the divers over age 40, dived moderate to high risk profiles on their last diving day.

3.3.10. Diving practices: distance to fellow diver at depth

No back-up bottles or other provisions for out-of-air emergencies are carried by these divers. Any such emergency is handled by an emergency swim to the surface, which puts the diver at high risk of decompression sickness and barotrauma. Also, if a diver becomes entangled in a net or experiences other difficulties, a fellow diver (or "buddy") can assist only if he is present and in sufficiently close proximity to recognise an emergency. The divers were asked how far they allowed themselves to become separated from their diving partner(s). Of the 299 respondents, 55.8% (189/339) indicated that they allowed separations of no more than 10 m, 20.9% (71/339) allowed separations of 11–20 m, and 1.2% (4/339) allowed more than 20 m. A large fraction of the respondents, 20.9% (71/339), indicated that they were not concerned about the location of their fellow diver, whereas 1.2% (5/339) stated that they dive alone. Divers reported in informal interviews that visibility at their normal working depth usually ranges between 4–6 m.

3.3.11. Diving practices: consumption of fluids

Dehydration may exacerbate risk of decompression sickness (Bookspan, 1995; Edmonds, Lowry, & Pennefather, 1992). The divers were asked how much fluid they consumed during a diving day. Thirty-three point three percent (111/333) consumed less than 1.5 L during a diving day, 62.2% (207/333) consumed 1.5 to 3 L, and 4.5% (15/333) consumed more than 3 L.

4. DISCUSSION

4.1. Questionnaire Development and Implementation

It was vigorously attempted to locate and interview all active divers in the 6 villages surveyed. This effort yielded interviews with 342 active divers. However, based on discussions with the village heads and our observations of the numbers and sizes of the boats in the villages (estimating the number of divers per boat), we estimate that the true total number of active divers using compressors in these villages is closer to 400. Diver absence due to the requirement for Thai males to complete military service is a possible explanation for having missed some divers. Although the Urak Lawoi are exempt from military service by Royal Decree, it was determined that 6 men were in the military at the time of the study, whereas 14 who had already completed military service were included among the 342 divers interviewed. These divers are thus only a representative sample of the overall population of compressed-air divers among the Urak Lawoi of the western coast of southern Thailand.

The contents of the questionnaires were carefully crafted to minimize misinterpretation by the Urak Lawoi and avoid bias. Care was taken to form the implementation team from public health workers that resided in the

Urak Lawoi villages. The implementation team was thus constituted to exploit the trust that had been developed over time between these workers and the Urak Lawoi. This provided the greatest possible assurance that thoughtful, complete, and honest answers to the survey questions were obtained and properly interpreted.

It is important in local culture to give a small token of appreciation after an interview. Accordingly, a shirt of the same style as the divers use for diving was given to each respondent. Each shirt had the diving safety message, "come up slowly from every dive" printed on the back in both Chaaw Lee and Thai languages. This may have created a bias in the responses to the question dealing with the speed of ascent (Question 40).

4.2. Diving Practices

Analyses of survey results confirm earlier reports (Sakboon, 1996) that a large number of the Urak Lawoi engage in diving practices that place them at considerable risk of decompression illness, including DCS. A significant number of divers exceed modern no-decompression limits and then fail to make decompression stops. They also tend to allow very short surface intervals before their repetitive dives. These factors were considered quantitatively in the present analyses of last dive day profiles for DCS risk. The model used was calibrated to reproduce DCS experience in a large and heterogeneous data set of air and nitrox dives (BIG292), but many profiles from the Sea Gypsy divers are much more stressful than any profiles in this data set. (The mean DCS incidence in BIG292 is 6.05%.) DCS risk estimates for these stressful profiles are consequently the results of model extrapolations into depth-time regions that are well beyond those in which the present model can be expected to provide accurate estimates of actual DCS risk. We are nonetheless confident in model ability to rank different profiles according to risk. The finding that a substantial fraction of last-day dive profiles incur estimated DCS risks greater than those associated with modern diving practice is therefore of particular concern.

This concern is potentiated by other factors not considered in the probabilistic analyses that also influence DCS risk and other aspects of overall diving safety. These factors include but are not limited to age, dehydration, multiple ascents in yo-yo diving, excessive ascent rates, and intense repetitive diving over consecutive days (Edmonds et al., 1992; Vann & Thalmann, 1993). All of these added factors are characteristic of Urak

Lawoi diving practice, but either could not be quantified for analysis or are beyond the scope of the model used. For example, present analyses provide estimates of DCS risk incurred during a single dive day considered in isolation from any preceding diving history, whereas actual risk is accumulated over multiple dive days on a typical dive trip. The latter cumulative risks are certainly greater—and probably substantially greater—than those estimated here. These factors are also associated with increased risks of aeroembolism, dysbaric osteonecrosis, and chronic neurological sequelae, which were not quantified in the present analyses. With the high incidence of reported pain among these divers, there is little doubt that the generally high estimated risks of DCS, potentiated by these added factors, are manifesting in high actual incidences of decompression sickness and other dive-related illness. The diving-associated morbidity and mortality of this diving community is addressed in an accompanying paper (Gold, Geater, Aiyarak, Wongcharoenyong, Juengprasert, Johnson, & Skinner, in press).

From a positive perspective, a large proportion of divers report that dive depths and bottom times have been decreasing over the past 10 years. Additionally, the fact that several safe diving practices are already being used by a considerable number of the diving community suggests positive influence from commercial, military, or recreational divers or from learning through experience.

Safe diving practices that require further reinforcement include slowing ascents from every dive, remaining aware of dive depth and bottom time, and making some kind of stop during ascent. The relationships between dive depth, bottom time, frequency of dives, and surface interval lengths need to be continually brought to the attention of the divers in a way that is easily understood and integrated into safer diving practice. These divers will not use modern decompression tables. Instead, the knowledge and experience embodied in those tables must be simplified into a few relatively simple rules. Development of such rules will require more detailed understanding of the dive profiles that are usually undertaken by these divers, as can be obtained using dive computers to record actual dives in real-time. The divers also require further training to dive with a diving buddy in close proximity. Finally, divers should be trained and equipped to carry a back-up air source, or a method to share air at depth in emergencies ("buddy breathing") needs to be developed and taught to the divers.

REFERENCES

Ball, R. (1993). Effect of severity, time to recompression with oxygen, and re-treatment in forty-nine cases of spinal cord decompression sickness. *Undersea Hyperbaric Medicine, 20*, 133–145.

Boffetta, P., Saracci, R., Kogevinas, M., Wilbourn, J., & Vainio, H. (1998). Occupational carcinogens. In J. Stellman (Ed.), *Encyclopaedia of occupational health and safety* (4th ed., 2.1–2.18). Geneva, Switzerland: International Labour Office.

Bookspan, J. (1995). *Diving physiology in plain English.* Kensington, MD, USA: Undersea and Hyperbaric Medical Society.

Butler, W.P. (1995). Maine's urchin divers: A survey of diving experience, medical problems, and diving related symptoms. *Undersea Hyperbaric Medicine, 22*(3), 307–313.

Dean, A.G., Dean, J.A., Coulombier, D., Brendel, K.A., Smith, D.C., Burton, A.H., Dicker, R.C., Sullivan, K.M., Fagan, R.F., & Arner, T.G. (1995). *Epi Info, version 6: A word-processing, database, and statistics program for public health on IBM-compatible microcomputers.* Atlanta, GA, USA: Centers for Disease Control and Prevention.

Edmonds, C. (1996) Pearls from the deep: A study of Australian pearl diving 1988–1991. *South Pacific Underwater Medical Society Journal, 26*(1), 2630.

Edmonds, C., Lowry, C., & Pennefather, J. (1992). *Diving and subaquatic medicine*. Oxford, UK: Butterworth-Heinemann.

Egstrom, G. (1993). SCUBA diving procedures and equipment. In P.B. Bennett & D.H. Elliott (Eds.), *The physiology and medicine of diving* (p. 25). London, UK: W.B. Saunders.

Elliott, D., & Moon, R. (1993). Manifestations of the decompression disorder. In: P.B. Bennett & D.H. Elliott (Eds.), *The physiology and medicine of diving* (pp. 481–505). London, UK: W.B. Saunders.

Engelhardt, R., & Rogers, P. (1991). Maritime-adaptive strategies in post-pleistocene Southeast Asia: An ethno-archaeological model for nature and distribution of archaeological sites. *Indo-Pacific Prehistory Association Bulletin, 16*(3), 177–192.

Engelhardt, R., & Rogers, P. (in press). The ethno-archaeology of Southeast Asian coastal sites: A model for the deposition and recovery of archaeological material. *ICANAS Conference Proceedings.*

Ganter, R., (1994). *The pearl-shellers of Torres Strait.* Melbourne, Australia: Melbourne University Press.

Gerth, W., & Vann, R. (1996). Development of Iso-DCS risk air and Nitrox decompression tables using statistical bubble dynamics models (Final Report, NOAA Award No. NA46RU0505). Silver Spring, MD, USA: National Oceanic and Atmospheric Administration.

Gerth, W., & Vann, R. (1997). Probabilistic gas and bubble dynamics models of decompression sickness occurrence in air and nitrogen-oxygen diving. *Undersea Hyperbaric Medicine, 24*(4), 275–292.

Gold, D. (1998). Indigenous fisherman divers (A case study). In J. Stellman (Ed.), *Encyclopaedia of occupational health and safety* (4th ed., pp. 66.3–66.4). Geneva, Switzerland: International Labour Office.

Gold, D., Geater, A., Aiyarak, S., & Juengpraesert, W. (1999). The indigenous sea gypsy divers of Thailand's west coast: Measurement of carbon monoxide in the breathing air. *Applied Occupational and Environmental Hygiene, 14*, 488–495.

Gold, D., Geater, A., Aiyarak, S., Wongcharoenyong, S., Juengpraesert, W., & Chuchaisangrat, B. (in press). *The indigenous fisherman divers of Thailand: Strengthening knowledge through education and information. Journal of Safety Research.*

Gold, D., Geater, A., Aiyarak, S., Wongcharoenyong, S., Juengpraesert, W., & Griffin, M. (*in press*). The indigenous fisherman divers of Thailand. Attitudes and awareness of hazards. *Journal of Safety Research.*

Gold, D., Geater, A., Aiyarak, S., Wongcharoenyong, S., Juengprasert, W., Johnson, M., & Skinner, P. (in press). The indigenous fisherman divers of Thailand: Diving-related mortality and morbidity. *International Journal of Occupational Safety and Ergonomics.*

Gorman, F. (1993). Management of diving accidents. In P.B. Bennett & D.H. Elliott. (Eds.), *The physiology and medicine of diving* (pp. 253–266). London, UK: W.B. Saunders.

Hinshiranan, N. (1996). *The analysis of moken opportunistic foragers' intragroup and intergroup relations.* Unpublished doctoral dissertation, University of Hawaii, Honolulu, USA.

Hogan, D. (1972) Men of the sea: Coastal tribes of Thailand's west coast. *Journal of the Siam Society, 60*(1), 205–235.

How, J., & Long, C.J. (1985). Rehabilitation of the paralyzed diver in Singapore. In J. Miller & J. Parmentier (Eds.), *Rehabilation of the paralyzed diver* (pp. 83–93). Bethesda, MD, USA: Undersea and Hyperbaric Medical Society.

Jones, J., Ramirez, S., & Doty, S. (1993). The pathophysiologic role of fat in dysbaric osteonecrosis. *Clinical Orthopaedics and Related Research, 296*, 256–264.

Kawashima, M., Tamura, H., Noro, Y., Takao, K., Kitano, M., Lehner, C., Taya, Y., Mano, Y., & Tsunosue, T. (1995). *Decompression sickness in divers, pathogenesis and prevention of dysbaric osteonecrosis* (Occasional Papers 25, pp. 37–46). Kagoshima City, Japan: Kagoshima University, Research Center for the South Pacific.

Kizer, K. (1982). Delayed treatment of dysbarism. *Journal of the American Medical Association, 247*, 2555–2558.

Lam, T., Yau, K., & O'Kelley, F. (1985). Dysbaric hazard of a new fishing method in Hong Kong: Case report. *British Journal of Industrial Medicine, 42*, 209–210.

Lee, H., Niu, K., Huang, K., Tsai, J., Shyu, R., Shiraki, K., Hong, S., & Lin, Y. (1994). Diving patterns of the fishermen in the Pescadores. *Undersea Hyperbaric Medicine, 21*(2), 45–58.

Lutz, W., Chalmers, J., Hepburn, W., & Lockerbie, L. (1992). *Health and community surveys (I and II).* London, UK: Macmillian Press.

Mayachiew. (1984). *Chaaw Lee at Banlamtong: A Study in cultural anthropology* (Thailand Archaeological Project). Bangkok, Thailand: Archaeological Office, Department of Fine Arts.

Melamed, Y., Shupak, A., & Bitterman, H. (1992). Medical problems associated with underwater diving. *New England Journal of Medicine, 236*(1), 30–35.

Mohri, M., Torii, R., Nagaya, K., Shiraki, K., Elsner, R., Takeuchi, H., Park, Y., & Hong, S. (1995). Diving patterns of the Ama divers of Hegura Island, Japan. *Undersea Hyperbaric Medicine, 22*(2), 137–143.

Moon, R., Vann, R., & Bennett, P. (1995). The physiology of decompression sickness. *Scientific American, 273*(2), 70–77.

Park, Y., & Hong, S. (1991). Physiology of cold water diving as exemplified by Korean women divers. *Undersea Biomedical Research, 18*(3), 229–241.

Sakboon, M. (1996, January 8). Coming up with ways to beat the bends. *The Nation (Bangkok)*, pp. A1–A3.

Thalmann, E., Parker, E., Survanshi, S., & Weathersby, P. (1997). Improved probabilistic decompression model risk predictions using linear-exponential kinetics. *Undersea Hyperbaric Medicine, 24*(4), 255–274.

Vann, R., & Thalmann, E. (1993). Decompression physiology and practice. In P.B. Bennett & D.H. Elliott (Eds.), *The physiology and medicine of diving* (pp. 376–432). London, UK: W.B. Saunders.

U.S. Navy, Naval Sea Systems Command. (1993). *U.S. Navy diving manual: Vol. 1. Air diving*. Washington, DC, USA: U.S. Government Printing Office.

Wade, C., Hayashi, E., Cashman, T., & Beckman, E.L. (1978). Incidence of dysbaric osteonecrosis in Hawaii's diving fishermen. *Undersea Biomedical Research, 5*(2), 137–147.

Wong, R. (1996). How safe is pearl diving. *South Pacific Underwater Medical Society Journal, 26*(1), 49–60.