DOI: 10.1007/s002670010168

Integrating Local and Scientific Knowledge: An Example in Fisheries Science

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ABSTRACT / Attempting to predict the spatial dynamics fish stocks, as required for management, is an ominous task given our incomplete understanding of biological and ecological mechanisms underpinning behavioral responses of fish. Large gaps still exist in our basic scientific knowledge. Nonetheless, the knowledge of fishers and fishery managers is not incorporated into our scientific analyses, even though such information is rich in observation since knowledge of fish behavior and distribution is a prerequisite for their profession. Combining such observations with more conventional scientific studies and theoretical interpretations provides a means by which we may bridge some gaps in our knowledge. Presented here is an example of how both local and scientific knowledge can be integrated in a heuristic model. The model, CLUPEX, is developed in the framework of a fuzzy logic expert system and uses linguistic statements written in natural language to capture and combine knowledge sources in the form of IF ... THEN rules. The rules are inferred from interviews with experts and fishery professionals including fishers, fishery managers, scientists, and First Nations people. The knowledge base, comprised of the set of rules, is flexible in the sense that it can easily be modified to add additional information or change current information. Using input pertaining to biotic and abiotic environmental conditions, CLUPEX uses the rules to provide quantitative and qualitative predictions on the structure, dynamics and mesoscale distribution of shoals of migratory adult herring during different life stages of their annual life cycle.

> When it comes to understanding fish behaviour and the many environmental factors that help determine and predict it, marine biologists must often take a back seat. This is hardly surprising. There are hundreds of times as many fishermen today than there are marine biologists, and their forebears were plying their trade and passing on their accumulated knowledge tens of centuries before anyone ever heard of marine biology. What is surprising is how little effort has been made by scientists to search out and record this information
>
> Robert Johannes
> *Words of the Lagoon*

Since many fisheries are at spatial scales of one to tens of kilometers and occur for periods of days to weeks, both fishers and fishery managers alike operate within the same mesoscale realm as the fish. By virtue of their profession, it is prerequisite that they have practical, applied knowledge regarding the distribution and behavior of the target species. Such a rich information source should not be ignored. Yet typically, traditional analytical fisheries science has considered local ecological knowledge as anecdotal, and for the most part it has remained absent from fish stock assessment or during development of management plans. In contrast, the approach of social science has been to emphasize the importance of local knowledge in a sociological and historical context. This approach has also been largely unsuccessful in directly incorporating this information into fisheries management (see Neis and others 1996, 1999 for an exception).

Information on the mesoscale distribution patterns of fish stocks is particularly lacking, and it is at this spatial and temporal resolution that studies are required to develop spatially explicit predictive models needed for management and to allow us to respond to change. Despite recent awareness of the profound importance of the spatial distribution of fish stocks to fisheries management (e.g., Hutchings 1996), much of our current understanding of fish distribution and behavior remains qualitative or highly uncertain. Combining the observations of fishery professionals with more conventional hard data from scientific studies and theoretical interpretations provides a means by which we may bridge some gaps in our knowledge (Figure 1).

Local knowledge does not lend itself well to mathematical representation and, consequently, traditional numerical modelling used for decision making may be unsuitable (Saila 1996). Here, an alternative way of representing and applying knowledge is described. A fuzzy logic (Zadeh 1965, 1973) expert system, named CLUPEX, is used to combine scientific information and knowledge of fishers to enhance our understanding of the spatial dynamics of herring shoals. Briefly, expert systems are a branch of artificial intelligence, providing theories and methods for automating intelligent behav-

KEY WORDS: Local ecological knowledge; Heuristics; Fuzzy logic; Prediction; Herring

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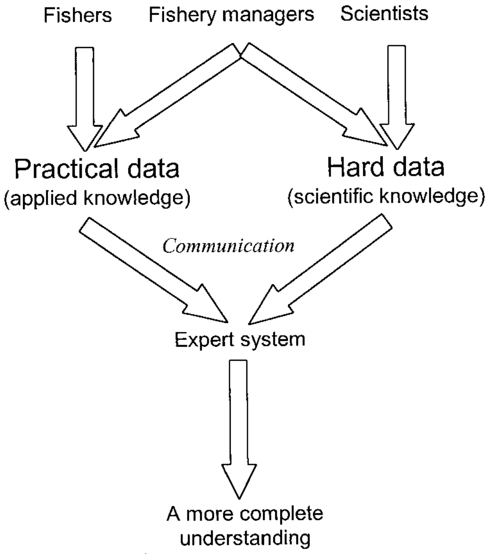

Figure 1. Combining sources of data (from Mackinson and Nøttestad 1998).

ior. They are computer programs that use heuristic rules to store knowledge, which is used to infer solutions and help provide assistance in solving complex problems normally handled by human experts. Although not as efficient as human experts, when constructed using fuzzy rules, they are able to mimic human decision-making based on common sense logic.

CLUPEX incorporates two fundamental sources of information on herring behavior and distribution patterns; (1) practical data: local knowledge from interviewed fishers, fishery managers, and First Nations people; (2) hard data: scientific information from fieldwork studies, published scientific literature sources, and interviewed fisheries scientists (Figure 1). All knowledge is incorporated in building the knowledge base, with the assumption of equality in the degree of belief in a piece of information from fishers, fishery managers, fishery scientists, First Nations people, or literature. In this way, the potential of all data sources is maximized (Mackinson and Nøttestad 1998). The information from all sources is recorded in a database that is cross-referenced directly to rules in the model.

Using input pertaining to the biotic and abiotic environmental conditions, CLUPEX uses heuristic rules to predict structure, dynamics, and mesoscale distribution of shoals of migratory adult herring during different stages of their annual life cycle. The predictions are generalized to two different herring species and may be used broadly to examine the impacts of shoal structure and distribution on management of herring fisheries. This paper is not concerned with technical details of the expert system (see Mackinson 2000 for details), rather it focuses on the collection and application of local knowledge in the construction of the system, highlighting how is integrated with quantitative data from field work and literature. The knowledge gleaned from interviews is primarily qualitative and descriptive in nature. It is used in CLUPEX to define rules linking biological and environmental factors to changes in spatial dynamics of herring shoals.

Interview Selection and Technique

A total of 30 formal interviews were conducted: eight with fishery scientists, seven with fishery managers nine with fishers, and six with First Nations people, all of whom were or are herring fishers.

With the exception of one gillnet fisher, who specifically undertook herring surveys, all fishers interviewed were seine fishers from British Columbia, Canada. They had a collective experience (CE) of approximately 270 fishing years and provided professional practical local knowledge. Seiners were specifically chosen as candidates in contrast to gillnetters or roe-on-kelp fishers, since seine-fishing typically involves an element of search and thus requires specific knowledge of fish distribution and movements. The First Nations CE amounted to approximately 290 fishing years.

Selection of interviewees was deliberately nonrandom. An attempt was made to interview those fishers who had the most experience fishing herring during different seasons, at different locations, and who held the respect of other fishers in the community. For this reason, progressive selection of interviewees was conducted by word of mouth, one candidate suggesting others to talk to. This method proved to be very successful. Fishery scientists and managers were selected based on their experience with herring. The current regional herring coordinator and three long-time British Columbia fishery managers (CE approx. 160 years) offered a more technical field-based perspective that complemented observations by fishers. Three herring scientists from the Pacific Biological Station, Department of Fisheries and Oceans (CE approx. 75 years), and a further five from Norway (Institute of Marine Research and University of Bergen; CE approx. 80 years) provided hard scientific data from field and experimental studies.

Typical interview duration was two hours but ranged from one to four hours. With two exceptions, all interviews were conducted on a separate individual basis at the preferred location of the candidate. For help with language interpretation, it was necessary on one occasion to interview two fishers together. In another instance, a meeting was held with the First Nations Sliammon band elders and included men and women who had traditionally been involved in herring fishing prior to the demise of their local herring stock.

Interviewees were asked to recount what they had observed regarding distribution and behaviour of herring and to offer possible explanations to account for their observations. All candidates were asked the same type of questions, although specific interviews were free-range or adaptive in the sense that the format and directness with which the questions were presented depended upon the context of discussion (Hart 1989). Allowing discussion to continue openly in this manner provided insight into many aspects that would have been overlooked by a questionnaire offering only a fixed set of responses. All interviewees were questioned on the same topics. On almost all occasions, new knowledge was acquired.

Using the same technique as Johannes (1978), the honesty and trustworthiness of the subjects' answers was tested by asking two types of questions at a convenient time during discussion. The first were questions to which the answer was already well-known (e.g., do herring feed during prespawning?). Responses to these questions were almost always the correct answer or that they did not know. The second type of question sounded plausible, but was one that the fishers were unlikely to be able to answer (e.g., how do birds locate herring schools sitting on the bottom during the day?). In virtually every instance, the response to this type of question was "I don't know," indicating that interviewees freely admitted to areas where they were lacking in knowledge.

Interviews were recorded by hand-written notes, then subsequently typed and sent to the candidate within 48 hours for verification of accuracy, corrections, and additions. Prior to interviewing, candidates signed an informed consent form (University of British Columbia) affirming that the information received would remain their property and that reference would be given directly to them when cited. Details of all candidates, together with a full transcript of their interviews, is recorded in a database.

Responses

There was clear demarcation in the type of responses given by different interviewees. Typically, fishers were particularly strong on observation, providing detailed accounts of school structure, distribution, and behavior, including school sizes, shape, density, depth distribution, association with specific features, ease of capture, and specific behavior patterns relating to season, tide, weather, fishing vessels, time of day, feeding, occurrence of predators. However, when asked why, they were generally reluctant or found it difficult to offer an interpretation for their observations. An attempt to elicit a rank order of factors they considered important in determining the observed shoal structure, distribution, and behaviors was unsuccessful. It was seemingly an almost impossible task for many and was subsequently abandoned for an alternative approach: the weight of evidence method (Mackinson 2000).

In contrast, fishery scientists were more familiar and at ease with offering interpretations for their observations or experimental findings and, for the most part, were able to assign an order of relative importance to the factors contributing to shoal structure, distribution, and behavior patterns.

Responses of fishery managers were more akin to those of fishers, being grounded firmly in field observation. However, due to the nature of their job, most were uncomfortable with ascribing behaviors to any particular factor. They tended to err on the side of caution and uncertainty, usually offering provisos and comments of exception to any of their observations. They were, however, more willing than fishers to offer potential interpretations, and it was apparent that these were frequently guided by scientific understanding from colleague fishery scientists.

Remarkably, there were no instances in which knowledge accumulated from any single source opposed another or diverged from that found in scientific literature. Information either complemented previous knowledge (from interviewees or literature) or added additional understanding.

Terms used by interviewees to describe shoals were frequently different than those used in scientific literature and, accordingly, some interpretation was necessary on my behalf. Despite this, with the exception of the shoal descriptor, 'fish direction', interviews did not identify any additional descriptors of shoal structure, dynamics, or distribution that were not previously identified from literature (Figure 2A). The point of departure between local knowledge and that obtained in the literature reflects the functional nature of the knowledge, particularly that of fishers. Numerically and proportionally more observations were directed to shoal features and factors influencing them that are particularly relevant to the ability to locate and capture shoals. For example, interviewees yielded more comments regarding biophysical influences on shoals including time of day, moonlight, topography and substrate, and weather conditions (Figure 2B) and how these influenced shoal

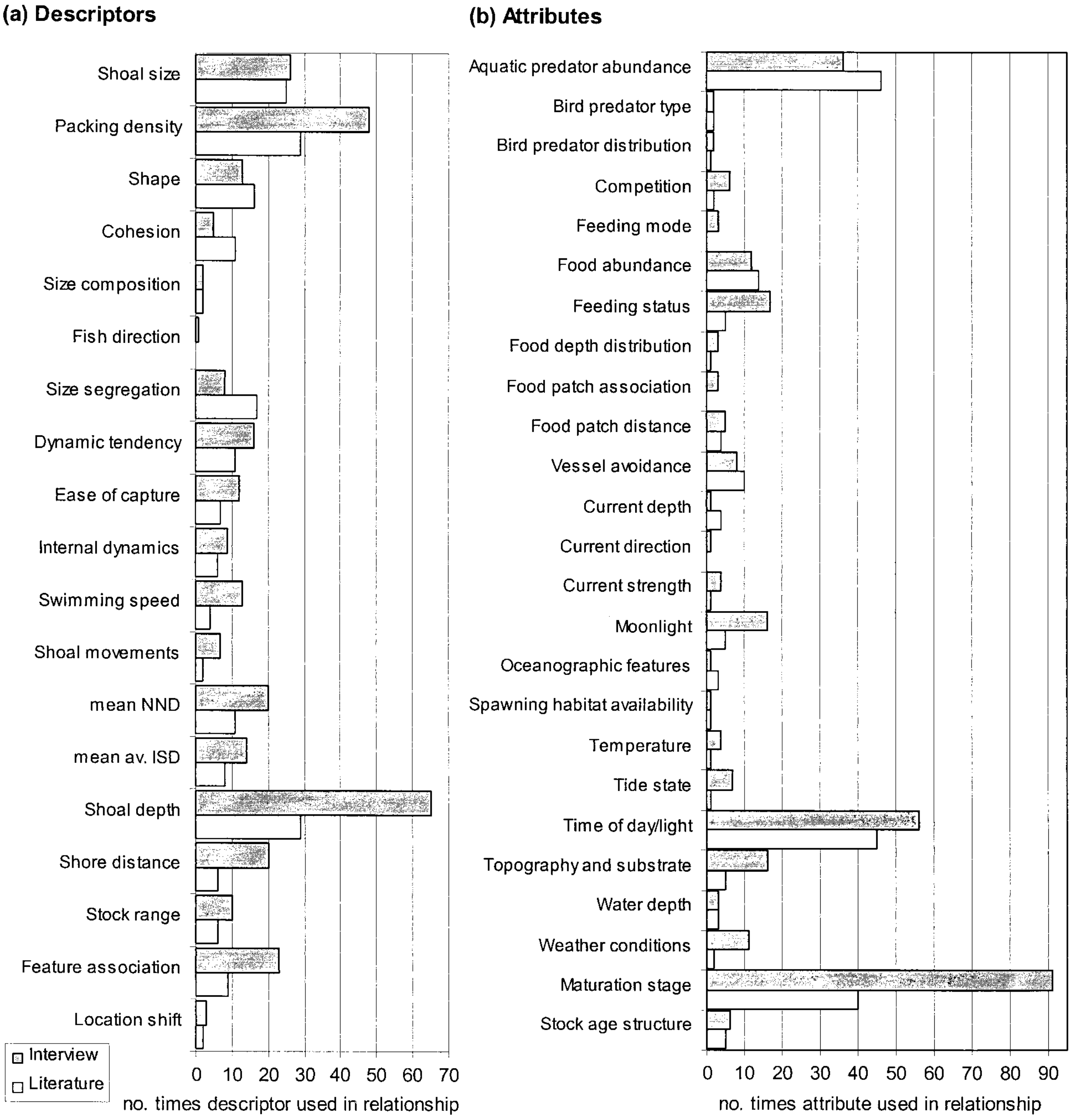

Figure 2. Comparison of descriptors and attributes derived from interviews and literature sources that were later used in forming rules. Abbreviations: mean NND = mean nearest neighbour distance; mean av. ISD = mean ISD (mean of the average intershoal distance). Attributes: factors affecting herring shoals. Descriptors: features used to describe herring shoal structure, dynamics, and distribution.

descriptors such as shoal size, depth distribution, packing density, ease of capture, speed, dispersion [mean nearest neighbor distance (NND) and mean of the average intershoal distance (ISD)], distance to shore, and association with features. It is noteworthy that the large number of comments on the effects of maturation stage reveal the fact that most herring fishers in British Columbia have extensive knowledge of prespawning herring, the season during which the commercial fishery occurs. Tables 1 and 2 provide a more specific categorisation of the relationships identified by interviews and literature.

Applying Knowledge: Forming Functional Relationships Using Rules

Heuristic rules written in natural language form the relationships between attributes influencing herring and descriptors of shoals (Tables 1 and 2). Rules have the form: IF a certain situation occurs, THEN a known outcome is likely, and they may contain several conditions in the IF part linked by AND, OR, NOT, and one or more elements in the THEN part linked by an AND. Since the goal is to because to draw a conclusion upon how behavioural responses to the influence of various combined factors produce changes in shoal structure, dynamics, and distribution, attributes are typically used in the IF part of rules and descriptors in the Then part. For example: IF food abundance almost nonexistent or sparse, THEN shoal cohesion low. The majority of rules are taken directly from the information source, while others are defined on best inference. For example, consider the information taken from literature:

> The best weather for fishin' on the hoom fishin' was after a good sou' west breeze, and then fall away. You know, drop away. Say a good ol' force 6 or 7 and then drop away. Drop away to about 2 or 3, 3 or 4. They used to stick their snouts in then and swim up then, they did. But on the real hoom fishin', on the full moon, that could be calm or anything, yit that allus seemed you got herrin'. On the October full moon, and November—anywhere about that time. Yis, you could git 'em in fine weather, except when that wun't very dark and there was a flat calm. You wun't git much then. ['Jumbo' Fiske (1905–1977) "probably the greatest herring skipper of the 20th century" (Butcher 1985)].

Together with the knowledge that Jumbo Fiske fished in an era where the method of herring fishing was drift-netting, two pieces of information might be inferred from his comments: (1) herring shoals were more dispersed and tended to rise in the water after storms; (2) when it is bright from a full moon, shoals are more dispersed. The interviews conducted with herring fishers and fishery mangers in British Columbia, plus other literature sources, support his comments and add further information. Some of the comments are given below. Note that the method of fishing by British Columbia herring fishers is by seine net. In contrast with the drift-net method, a scattered distribution of fish results in poor catches.

On the Effects of Weather

"If the weather is bad then the herring shoals go deep to hide. They may even stop the diurnal migration" (J. Malatestinic and J. Reid personal communication).

"In big storms the herring disappear—its thought that they may go deep at this time" (B. Armstrong personal communication).

"When there is a big storm the herring may scatter and disappear" (D. Chalmers personal communication).

"A strong blow breaks fish up—scatter to bottom. It tends to spread fish out" (J. Boroevich personal communication).

"On calm days, most rudd oriented toward shore. On windy days, fish stayed deeper in the water" (Keenlyside 1955).

"If weather is bad close to spawning then schools get disrupted" (L. Gordon personal communication).

"Bad weather tends to scatter them out" (G. Savard personal communication).

"Weather changes the distribution. If it is bad then it clearly interrupts the pattern of what the herring are doing" (G. Thomas personal communication).

"NW winds tend to scatter the fish" (M. Carr personal communication).

"Catches of drifter boats increase significantly during bad weather at pre-spawning—presumably because the fish disperse. When fish are aggregated in schools they get poor catches" (Wood 1930)

On the Effects of the Moon

"Usually the herring come up and skimmer out but if it is a full moon the herring don't come up so far and they spread out a lot" (J. Boroevich personal communication).

"Fish come up and skimmer out at night. The moon scatters the fish more" (M. Carr personal communication).

"Moon causes the fish to skim out very thin in the evening time" (A. Hunt personal communication).

"If there is a bright moon the fish spread out fast and its difficult to catch them" (J. Reid personal communication).

"It is poor fishing on a full moon. The fish are not so concentrated" (J. Lenic personal communication).

"The moon has a lot to do with it. They stay down when the moon is full. Best to catch them just before the moon comes out in reduction days because when the moon comes out they go to skimmers quickly and go too deep" (V. Wilson personal communication).

"Catches of herring vary with moon phase and the depth of shoals may be lower when there is a moon. Clark (1956) reported that Californian sardine fishermen tied up during full moon period because they caught so few fish" (Blaxter and Holliday 1969).

In summarizing the knowledge presented above, two rules are inferred: (1) IF weather bad (storms and high winds), THEN relative shoal depth *bottom* AND nearest

Table 1. Summary table of relationships between attributes and descriptors used in CLUPEX

	Descriptor						
	Structure						
Attributes	Shoal size	Pack dens	Shape	Cohes	Size comp	Fish dir	Size seg
External—biotic							
Aquatic predator abundance	√ (5,16)	√ (7,8)	√ (3,8)	√ (0,7)			
Bird predator type					√ (2,2)		
Bird predator distribution		√ (2,1)					
Competition	√ (2,1)	√ (1,0)	√ (0,1)				
Feeding mode							
Food abundance	√ (3,3)	√ (4,5)		√ (0,1)			
Feeding status	√ (4,0)	√ (6,2)					
Food depth distribution							
Food patch association							
Food patch distance							
External—abiotic							
Vessel avoidance							
Current depth							
Current direction						√ (1,0)	
Current strength			√ (1,1)				
Moonlight		√ (7,2)					
Oceanographic features							
Spawning habitat availability	√ (1,1)						
Temperature							
Tide state							
Time of day/light		√ (13,6)	√ (1,1)				√ (4,13)
Topography and substrate							
Water depth							
Weather conditions							
Internal—biological							
Maturation stage	√ (11,4)	√ (8,5)	√ (8,5)	√ (5,3)			√ (4,4)
Stock age structure							

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[a] Numbers in parentheses (x, y): x = no. of interview records noting relationship. y = no. of literature sources noting relationship.

Descriptors—parameters characterizing structure, dynamics, and distribution of shoals. **Attributes**—factors influencing herring shoal structure, dynamics and distribution. **Abbreviations:** Pack dens—packing density; Cohes—shoal cohesion; Size comp—size composition of fish in shoal; Fish dir—shoal direction with respect to current; Dyn tend—dynamic tendency; Catch ease—ease of capturing a shoal; Int dyn—internal dynamics (schooling or

Table 1. (*Continued*)

Descriptor											
Dynamics					Distribution						
Dyn tend	Catch ease	Int dyn	Swim speed	Shoal move	NND	mean ISD	Shoal depth	Shore dist	Stock range	Feat assoc	Loc shift
√ (4,2)		√ (2,2)	√ (2,0)		√ (3,0)		√ (7,1)				√ (3,2)
√ (1,0)		√ (1,0)	√ (1,0)								
√ (1,0)			√ (2,0)								
					√ (4,5)						
√ (2,3)		√ (3,0)		√ (2,0)							
							√ (3,1)				
										√ (3,0)	
						√ (5,4)					
			√ (0,2)		√ (2,1)		√ (6,7)				
							√ (1,4)				
										√ (3,0)	
	√ (6,1)						√ (3,2)				
										√ (1,3)	
									√ (4,1)		
							√ (7,1)				
√ (0,1)	√ (2,5)	√ (1,2)	√ (2,0)	√ (1,1)	√ (1,2)	√ (1,4)	√ (18,4)	√ (12,6)			
										√ (16,5)	
√ (1,0)							√ (2,3)				
					√ (5,1)		√ (6,1)				
√ (7,5)	√ (4,1)	√ (2,2)	√ (6,2)	√ (4,1)	√ (4,2)	√ (8,0)	√ (12,5)	√ (8,0)		√ (0,1)	
									√ (3,3) + (3,2)		

shoaling); Swim speed—mean swimming speed of shoal; NND—mean nearest neighbour distance; mean ISD—mean of the average interschool distance (distance from one shoal to all other shoals in location; Shore dist—relative distance to shoreline; Stock range—fulfillment of potential stock range; Feat assoc—association with physical/oceanographic features; Loc shift—likelihood of being displaced from feeding location.

Table 2. Descriptor and attribute interrelations used in CLUPEX

	Shoal size	Packing density	Shape	Cohesion	Fish direction
Shoal movements	√ (3,2)				√ (2,1)
Relative stock size	√ (6,2)				
Fish length		√ (1,2)			
Mean swimming speed		√ (1,1)	√ (1,3)		√ (1,0)
Shoal size		√ (0,1)		√ (0,1)	
Shoal depth			√ (1,1)		
Extent/Area		√ (2,0) + (3,0) + (2,0) + (2,1)			
Shore distance	√ (1,0)				
Food size/abundance[a]					

[a] Attribute interrelation.

neighbour distance of shoals *high.* (2) IF time of day is dusk OR night AND state of the moon is full and bright, THEN shoal depth *mid-range* AND packing density *very low* AND ease of capture *very low.*

The heuristic rules capture knowledge contained in linguistic expressions given by interviewees. By computing with words (L. Zadeh personal communication 7 December 1998, UBC, Green College lecture series), it is possible to form complex, yet still descriptive and transparent relationships between attributes and descriptors.

In the example rules above, the terms in italics represent member sets of shoal descriptors defined as fuzzy variables (Figure 3). While not all rules in the model use fuzzy definitions, the connection between fuzzy variables and their member sets and the processes of fuzzy inferencing and defuzzification provides the direct link for combining quantitative and qualitative knowledge and expressing associated uncertainty. Fuzzy rules are the key to achieving quantitative output from qualitative understanding described in the rules using linguistic expressions (for more details see Mackinson 2000). They avoid the impractical and almost impossible task of attempting to relate information in a purely quantitative way, while still being able to describe continuous functions.

An important potential shortcoming that might be perceived from the method of pooling collective knowledge into rules is the possibility of having pieces of knowledge from different experts that are inconsistent or even conflicting. This aspect is of taken in to consideration in two ways. First, where apparently conflicting information was given during interviews, subsequent interviewees were questioned specifically on that subject in an attempt to clear up potential inconsistencies. Second, where information did conflict, individual rules were incorporated to capture each piece of knowledge. The confidence in each of the rules was later weighted using a "weight of evidence" approach (Mackinson 2000) that determines the effect on the overall results. Those with a low evidence contribute little to the final conclusions.

Quantitative Output from Heuristic Rules

CLUPEX makes a variety of quantitative and qualitative predictions on the spatial dynamics of herring shoals. Using the example of diurnal changes in the shoal packing density and depth distribution, and the effects of the moon as previously discussed, we see that CLUPEX is capable of predicting the patterns that are generally observed in nature (Figure 4). The predicted diurnal changes in shoal structure and distribution confer well with the typical type-I pattern (Nielson and Perry 1990) observed in herring throughout most of their adult life cycle (e.g., Radakov 1960, Blaxter and Holliday 1969, Thorne 1977, Blaxter 1985, Buerkle and Stephenson 1990, McCarter and others 1994, Mackinson and others

Table 2. (*Continued*)

Size segregation	Internal dynamics	Mean swimming speed	Catchability (q)	Stock area/range	NND	Mean ISD	Feature association	Feeding mode
√ (1,2)							√ (3,1)	
			√ (0,11)	√ (3,2)	√ (0,1)	√ (2,0)		
		√ (2,4)						
	√ (1,1)							
		√ (1,0)	√ (0,6)					
								√ (1,2)

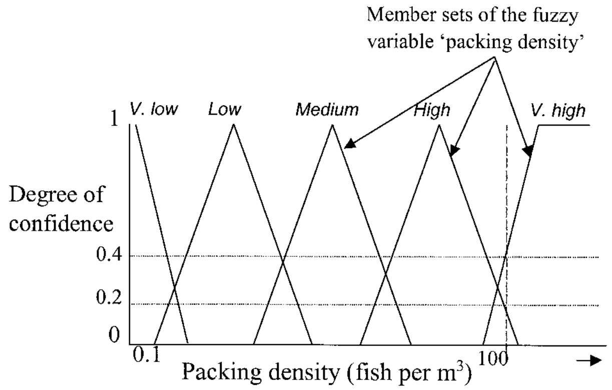

Figure 3. Membership functions of sets on the fuzzy variable "packing density." The member sets (also sometimes called subsets) are the linguistic concepts; very low, low, medium, high, and very high. The slope and degree of overlapping of the memberships functions is the key element determining how unique or "fuzzy" the sets are. The degree of confidence on the *y* axis shows our degree of belief in the linguistic concepts. For example, when packing density is 100 fish/m^3, we are 0.2 confident that packing density is high and also 0.4 confident that it is very high. In an expert system both pieces of information are used simultaneously to make conclusions, thus avoiding the simplistic notion that something is or is not true, when in fact it may be both to different degrees.

1999). Surveys on the Pacific coast during 1971–1982 found daytime herring schools at 40 m deep dispersing to form relatively uniform, widespread, single target layers between 10 and 30 m during the night (Mathisen and others 1983). Thorne (1977) noted that at night, school volume was higher and herring were dispersed at lower densities and over wider areas with considerably less patchiness. Mean daytime densities were 9–10.4 fish per m^3. During nights with a bright moon, there is a modification to the typical diurnal pattern with shoals rising early and dispersing rapidly (interviews with Boroevich, Carr, Hunt, Reid, Lenic and Wilson). For further, more detailed example applications of CLUPEX, the reader is referred to Mackinson (1999, 2000).

Discussion

Although the magnitude and relevance of local knowledge in resource management has been recognized for some time (Johannes 1978, Dahl 1989, Maguire and others 1994, Pitcher and Hart 1998), a mismatch between that which is known and that which is used for any practical sense remains. Resource management decisions are typically based on detailed, yet limited studies of a more traditional scientific nature—hard science. Despite recognizing the obvious need to incorporate local knowledge into science and management, two important barriers still exist: the reluctance to give it respect equal to that given to hard science, and the inability to incorporate it in a holistic meaningful way (Mackinson and Nøttestad 1998). The former is deep rooted and requires a fundamental

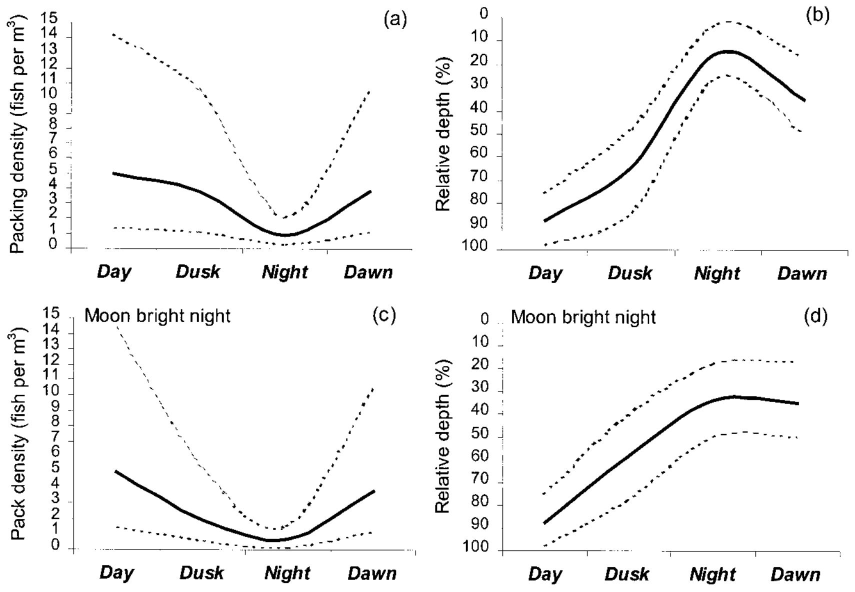

Figure 4. Predicted "typical" diurnal changes in herring shoal structure and distribution (a and b) and modifications during moon bright nights (c and d). Solid line is average predicted value while dashed lines indicate minimum and maximum of the range.

change in our scientific approach, a point recognized by Chambers (1980), who comments "the most difficult thing for an educated expert to accept is that poor farmers may often understand their situations better than he does. . . . It is difficult for some professions to accept that they have anything to learn from rural people, or to recognise that there is a parallel system of knowledge to their own which is complementary, that is usually valid and in some aspects superior."

Recently, there have been several attempts at achieving the latter. For example, Neis and others (1996) conducted a thorough series of interviews with cod fishers in Newfoundland, the results of which convincingly demonstrated that local knowledge, formerly treated as anecdotal and then overlooked, was capable of contributing detailed scientific information on stock structure, changes in catchability, abundance during a closed fishery, and potential impacts of a reopened capelin fishery on northern cod recruitment. Specific knowledge of fishers also included awareness of the relationships between season, winds, tides, water temperature, the presence of other species, and the ease of capture of fish. Moreover, the relationship between fish size, value, and effort means fishers take note of the size distribution of fish (Neis 1992). Case studies by Pinkerton and Weinstein (1995) highlight how local knowledge can be applied to great benefit under a system of community based management. In a study of the Pacific herring bait fishery, Schweigert and Linekin (1990) also recognize the value of local knowledge. Questionnaires were used to obtain information on spatial distribution of nonmigratory herring that are not sampled or assessed as part of the routine monitoring of the major adult migratory populations. The approach shown here complements these approaches, but goes one step further by combining both local and scientific knowledge using a formal framework in the form of an expert system.

Despite potential biased perceptions of resource abundance and their impacts, knowledge of fishers can be a fountain of information (e.g., Johannes 1978). Frequently their knowledge is compiled over time based on that of their parents, grandparents, and others with whom they have fished. The interviews in this study reveal that fishers closely observed physical environmental conditions and temporal changes resulting in variation in distribution, size, and ease of capture of herring schools. However, in contrast to interviewed scientists and fishery mangers, fewer were prepared to suggest behavioral interpretations for their observations. With the exception of several enthusiastic individuals, it did not appear "necessary" that they should ask why? Neis and others (1996) found a similar response from interviews with cod fishers; ". . . fishers' knowledge of fish stocks is primarily acquired to optimise catches while minimising effort. Therefore, they tend to closely observe those environmental features which are linked to fishing success: seasonal movements, habitat preferences, feeding behaviour and abundance dynamics; as well as those physical attributes that affect fish distribution, the performance of gear and fishing time: wind direction, currents, water temperature and clarity, bottom characteristics and local assemblage structures, as well as gear fouling."

Remarkably, there was no conflict in the information obtained from fishers, scientists, and literature sources that could not be explained by observations at different scales. More unique instances of information were obtained occasionally from fishers. Information from scientists, fishery mangers, field observations, and literature accounts tended to support and complement knowledge given by fishers rather than extend it. Overall, the knowledge gained through interviews contributed critical information on aspects of herring behavior and distribution that are not easily experimented upon and have not been reported from scientific field studies.

On consideration of the responses to specific questions used as test controls for assessing the trustworthiness of answers, it was deemed that all information relating to distribution and structure of shoals was accurate according to memory. Although on several occasions there were tendencies for stories, when asked a specific question, the response of interviewees was straightforward and no attempt was made to conceal ignorance of any subject. Where peculiar or unique observations were made, these were deliberately verified with other subjects in subsequent interviews. Further validation was conducted during the field surveys, during which an attempt was made to verify interviewees' observations.

Sometimes a problem is so compelling and the consequences of no action are so serious that action must be taken in spite of (or because of) the shortcomings in scientific knowledge. Conventional fisheries methodologies are often too restrictive with regard to the type and detail of ecological information that is admissible for use in evaluating problems. A less restrictive paradigm is needed, one that will admit more information and have greater explanatory power (Bakun 1996). Application of heuristics makes it possible to combine various knowledge sources in a series of rules, written in natural language. Heuristic models in general offer great potential, a point emphasized by Hilborn and Mangel (1996), who comment, "although the output of most models is numerical, the most influential models are the ones in which the numerical output is not needed to guide the qualitative understanding." Through building and testing we move toward practicality, recognizing that decisions based on qualitative and sometimes incomplete knowledge are still better than making decisions without any understanding (Saila 1996).

Typically, expert systems are suited to solving problems that cannot be solved using a purely algorithmic approach: those that have an irregular structure, contain incomplete, qualitative or uncertain knowledge, are considerably complex, and where solutions must be obtained by reasoning from available evidence and sometimes making "best guesses" (Dabrowski and Fong 1991). Recognizing that much of our understanding of fish ecology, ecosystem effects of fishing, and social and economic effects of fishing exhibit these qualities, it is somewhat surprising that the use of expert systems and fuzzy logic has been infrequently used in fisheries. In a review of fishery related expert systems, Saila (1996) offers a list of only 18 noteworthy systems. Of these, only two (Aoki 1989, Fuchs 1991), both of which are nonfuzzy systems, consider interactions between fish and environmental factors.

Application of fuzzy logic provides the ability to map linguistic expressions on to numerical variables, or practical knowledge onto hard data, thus integrating both qualitative and quantitative information and bringing these two worlds into sync (McNeill and Freiberger 1993). Humans perceive the precise in a fuzzy way, and it is this ability to summarize information into classes (fuzzy sets) that separates human intelligence from machine intelligence (Zadeh 1973). Zadeh (1999) states that "Fuzzy logic is the logic of perceptions." Several important benefits are realised by using a fuzzy approach in CLUPEX. Definition of fuzzy sets allows CLUPEX to capture the vagueness and uncertainty associated with language that is not possible with conventional mathematical tools whose crisp definitions force break points. By allowing us to assign degrees of confidence simultaneously to various possible options (defining membership functions of a fuzzy set), fuzzy logic provides an organized method for dealing with imprecision of data. It makes it possible to take in to account the grey areas of data, thus providing the ability to more closely reflect the real world.

CLUPEX is capable of predicting state-dependent, mesoscale spatiotemporal changes in the structure, dynamics, and distribution of herring shoals, features that have important implications to fisheries management in relation to fish stock structure, assessment, resilience, and harvest control (Mackinson 1999). However, of particular interest here, is the more general value of the approach as a formal framework for combining local and scientific knowledge. This paper has attempted to show not only the value of local knowledge to fisheries science and management, but also to demonstrate a methodology by which it may be incorporated with more traditional "hard data" and applied to achieve quantitative results. One obvious benefit of utilizing nonscientists' knowledge combined with more typical scientific data is greater acceptability of fisheries science and the recommendations that it offers. Stake-holders who may directly be influenced by management actions can contribute information central to the formulation of scientific recommendations to management. Intuitively, this involvement provides a sense of worth and pride and thus may be instrumental in fostering greater responsibility of fishers to the resource.

Acknowledgments

Sincere thanks to all those who participated in interviews; it was wonderful to learn from you all. Funded by the International Council for Canadian Studies.

Literature Cited

Aoki, I., T. Inagaki, I. Mitani, and T. Ishii. 1989. A prototype expert system for predicting fishing conditions of anchovy of the coast of Kanagawa Prefecture. *Bulletin of the Japanese Society for Fisheries and Oceanography* 55(10):1777–1783.

Bakun, A. 1996. Pattern in the ocean: Ocean processes and marine population dynamics. California Sea Grant College System. 323 pp.

Blaxter, J. H. S. 1985. The herring: A successful species? *Canadian Journal of Fisheries and Aquatic Science* 42(Suppl. 1):21–30.

Blaxter, J. H. S., and F. H. Holliday. 1969. The behaviour and physiology of herring and other clupeids. *Advances in Marine Biology* 1:261–393.

Buerkle, U., and R. L. Stephenson. 1990. Herring school dynamics and its impact on acoustic abundance estimates. Proceeding of the International Herring Symposium. October 1990. Anchorage, Alaska Sea Grant, pp. 185–207.

Butcher, D. 1985. The Driftermen. Tops'l Books, UK. 152 pp.

Chambers, R. 1980. The small farmer is a professional. *Ceres* March–April:19–23.

Clark, F. N. 1956. Average lunar month catch of sardine fishermen in southern California 1932–33 through 1954–55. *California Fisheries and Game* 42:309–323.

Dabrowski, C. E., and E. N. Fong. 1991. Guide to expert system building tools for computers. Special Publication 500-188. National Institute of Standards and Technology, Gaithersburg, Maryland 141 pp.

Dahl, A. L. 1989. Traditional environmental knowledge and resource management in New Caledonia IUCN, World Conservation Union, Gland, Switzerland. *in* R. E. Johannes, (ed), Traditional ecological knowledge: A collection of essays. Pages 57–66

Fuchs, F. 1991. An expert system for analysing relationships between fish and the environment, International Council for the Exploration of the Sea, C.M. 1991/D:5, 6 pp.

Hart, A. 1989. Knowledge acquisition for expert systems. New technology modular series. Kogan Page, London, 243 pp.

Hilborn, R., and M. Mangel. 1997. The ecological detective: Confronting models with data. Princeton University Press, Princeton, New Jersey, 315 pp.

Hutchings, J. A. 1996. Spatial and temporal variation in the density of northern cod and a review of the hypotheses for the stock's collapse. *Canadian Journal of Fisheries and Aquatic Sciences* 53:943–962.

Johannes, R. E. 1978. Words of the lagoon: Fishing and marine law in the Palau district of Micronesia. University of California press, Berkeley, 245 pp.

Keenlyside, M. H. A. 1955. Some aspects of the schooling behaviour of fish. *Behaviour* 8(2–3):183–248.

Mackinson, S. 1999. Integrating knowledge to predict spatial dynamics of herring shoals using an expert system. PhD thesis. Fisheries Centre, University of British Columbia, Vancouver, British Columbia, 234 pp.

Mackinson, S. 2000. An adaptive fuzzy expert system for predicting structure, dynamics and distribution of herring shoals. *Ecological Modelling* 126:155–178.

Mackinson, S., and L. Nøttestad. 1998. Combining local and scientific knowledge. *Reviews in Fish Biology and Fisheries* 8(4):481–490.

Mackinson, S., L. Nøttestad, S. Guénette, T. J. Pitcher, O. A. Misund, and A. Fernö. 1999. Cross-scale observations on distribution and behavioural dynamics of ocean feeding Norwegian spring spawning herring (Clupea harengus L.). *ICES Journal of Marine Science* 56:613–626.

Maguire, J.-J., B. Neis and P. R. Sinclair. 1994. What are we managing anyway?: The need for an interdisciplinary approach to managing fisheries ecosystems. International Council for the. Exploration of the Sea, CM-1994/T:48

Mathisen, O. A., N. A. Lemberg, and R. L. Johnson. 1983. Hydroacoustic indices as input to dynamic management systems of fish stocks. FAO Fisheries Report No. 300, pp. 223–231.

McCarter, B.,, D. E. Hay, P. Whither and R. Kieser. 1994. Hydroacoustic herring survey results from Hecate strait, November 22–December 2, 1993. *W. E. Ricker* Cruise 93HER. *Canadian Manuscript Report of Fisheries and Aquatic Sciences* 2248, 40 pp.

McNeill, D., and P. Freiberger. 1993. Fuzzy logic. Touchstone, New York, 320 pp.

Neilson, J. D., and R. I. Perry. 1990. Diel vertical migrations in marine fishes: An obligate or facultative process? *Advances in Marine Biology* 26:115–168.

Neis, B. 1992. Fishers' ecological knowledge and stock assessment in Newfoundland. *Newfoundland Studies* 8(2):155–178.

Neis, B., L., Felt, D. C., Schneider, R. Haedrich, J. Hutchings, and J. Fischer. 1996. Northern cod stock assessment: What can be learned from interviewing resource users? DFO Atlantic Fisheries. Research document 96/45, 28 pp.

Neis, B., L. Felt, R. L. Haedrich, and D. C. Schneider. 1999. An interdisciplinary method for collecting and integrating fishers' ecological knowledge into resource management. Pages 217–238 *in* D. Newell and R. Ommer (eds.), Fishing people, fishing places: Traditions and issues in Canadian small-scale fisheries. University of Toronto Press, Toronto, 374 pp.

Pinkerton, E., and M. Weinstein. 1995. Fisheries that work. Sustainability through community based management. A report to the David Suzuki Foundation, Vancouver, British Columbia, 199 pp.

Pitcher, T, J., and P. J. B Hart. 1998. Reinventing fisheries management. Chapman and Hall, London.

Radakov, D. V. 1960. Observations on herring during a voyage of a research submarine 'Severyanka.' (In Russian, Marine Laboratory, Aberdeen trans. No, 718.) *Byull. Okeanogr. Kom. Akad. Nauk. S.S.S.R.* 6:39–40.

Saila, S. B. 1996. Guide to some computerised artificial intelligence methods. Pages 8–37 *in* B. A. Megrey and E. Moksness (eds.), Computers in fisheries research. Chapman and Hall, London.

Schweigert, J. F., and M. Linekin. 1990. The Georgia and Johnstone straits herring bat fishery in 1986: Results of a questionnaire survey. *Canadian Technical Reports of Fisheries and Aquatic Sciences* 1721, 44 pp.

Thorne, R. E. 1977. Acoustic assessment of Pacific hake and herring stocks in Puget Sound, Washington and southeastern Alaska. *Rapports et Procés-Verbeaux des Réunion du Conseil International pour l' Exploration de la Mer* 177:265–278.

Wood, H. 1930. Scottish herring shoals: Pre-spawning and spawning movements. *Fisheries, Scotland, Scientific Investigations,* 1930; I.

Zadeh, L. A. 1965. Fuzzy sets. *Information and Control* 8(3): 338–353.

Zadeh, L. A. 1973. Outline of a new approach to the analysis of complex systems and decision processes. *IEEE transactions on systems, man and cybernetics* SMC-3(1):28–44.

Zadeh, L. A. 1999. From computing with numbers to computing with words: from manipulation of measurements to manipulation of perceptions. The second international conference on intelligent processing and manufacturing of materials. Honolulu, Hawaii, 10–15 July 1999. *IEEE Transactions* (in press).