Contributions of local knowledge to the physical limnology of Lake Como, Italy

Sarah Laborde[a,b,1], Jörg Imberger[a], and Sandy Toussaint[b]

[a]Center for Water Research; and [b]Anthropology and Sociology, University of Western Australia, 35 Stirling Highway, Crawley 6009, Australia

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This article shows how local knowledge may be valuably integrated into a scientific approach in the study of large and complex hydrological systems where data collection at high resolution is a challenge. This claim is supported through a study of the hydrodynamics of a large lake where qualitative data collected from professional fishers was combined with theory to develop a hypothesis that was then verified by numerical modeling. First the fishermen's narratives were found to describe with accuracy internal wave motions that were evident in water column temperature records, which revealed their practical knowledge of the lake's hydrodynamics. Second, local knowledge accounts emphasized the recurrent formation of mesoscale gyres and return flows in certain zones of the lake in stratified conditions, which did not appear in the physical data because of limitations of sampling resolution. We hypothesized that these features developed predominantly because of the interaction of wind-driven internal motions with the lake's bathymetry, and the Earth's rotation in the widest areas of the basin. Numerical simulation results corroborated the fishers' descriptions of the flow paths and supported the hypothesis about their formation. We conclude that the collaboration between scientific and local knowledge groups, although an unusual approach for a physical discipline of the geosciences, is worth exploring in the pursuit of a more comprehensive understanding of complex geophysical systems such as large lakes.

interdisciplinary science | internal waves | drift-net fishing | ethnographic interviewing | hydrodynamic modeling

The hydrodynamics of stratified lakes is highly relevant to ecosystem governance (1, 2) and also, in many lakes, to the practices of professional fishers. Whereas fundamental and applied limnologists collaborate to advance the field of physical limnology, the potential contribution of fishers' local practical knowledge has not been addressed.

Local knowledge (LK) also known as traditional ecological knowledge and, in some cases, indigenous knowledge (3) arises from the way people live and work in their local environment; it is embedded in their long-standing practices, skills, traditions, and narratives, spanning across a broad range of temporal and spatial scales. Whereas a few decades ago most research on aquatic environments was conducted on field sites that were located near the researchers' university or research center, today the advances of telecommunication technologies and international scientific collaboration allow much environmental research to be conducted with limited time in the field (a comparative look at editions from the 1960s and the 2000s of a journal such as *Limnology and Oceanography* illustrates this point), limiting at the same time researchers' exposure to LK.

In the last decade, however, there has been an increasing and explicit academic interest for LK in the science and governance of environmental systems, particularly in ecology (4–6). Despite a trend that has shown the potential benefits of considering LK in environmental research (7), studies that attempt to do so are still few, especially in the physical sciences, because (*i*) LK is generally qualitative, requiring social science methods to be accessed and interpreted; and (*ii*) there is no way to quantify the uncertainty of information obtained through LK, making it difficult to integrate with a natural science framework (8).

In this article we show how local knowledge may be useful also in the physical geosciences. We use fishermen's practical knowledge to formulate a hypothesis that, after validation by numerical modeling, led to an improved understanding of the hydrodynamics of a large subalpine Italian lake. The article starts by introducing the lake, basic aspects of its hydrodynamics, and relevant practices of the fishermen. We then compare some of the heuristics fishermen discussed with records of water column temperature and wind data to establish the coincidence of the two types of knowledge, scientific and local, with regard to large-scale physical processes in the lake. We then address some of the fishermen's accounts of recurrent gyres and return flows in certain zones of the lake, mesoscale hydrodynamic processes that were not evident in the quantitative data because their spatial scale was smaller than the sampling resolution. We turn to results from basin-scale numerical modeling simulations to confirm fishermen's observations of these flow features and to discuss their formation. We conclude by discussing the broader methodological implications of this study for environmental science.

Lake Como (Lario) is a deep and narrow lake stretching 45 km between the mountain regions of the Alps and the agro-industrial plains of the Brianza. Its morphology and wind field are complex as the lake has three arms that extend, respectively, north (alto lago), southeast (ramo di Lecco), and southwest (ramo di Como). Regular winds on the lake are the Tivano, a light morning northerly wind, and the Breva, an afternoon southerly; the Vento is a violent and less-predictable northerly wind that may last several days. A seasonal thermal stratification develops in spring in the lake's water column, strengthens throughout summer, and persists until late autumn and, most years, also throughout winter in a weak and deep form (9). The zone of rapid temperature change in the water column (the metalimnion, encompassing the thermocline that marks the sharpest temperature gradient) that separates the upper mixed layer (the epilimnion) from the denser bottom layer (the hypolimnion) deepens through the year, from the near surface in spring to about 15 m in summer, through to 30 to 40 m in autumn (Fig. 1*A*).

Water column temperature records evidence wind-driven internal waves along the lake's thermocline, in particular an internal uninodal vertical seiche (see schematic Fig. 1*B*) that is triggered by northerly wind events, has a period of 3 to 5 d and can lead to large interface displacements. Spectra of isotherms displacements also evidence a higher vertical mode internal wave with a phase keyed to the diurnal wind patterns. The lake's main inflows drain water from alpine catchments in the north and generally intrude as interflows during the stratified period, and interplay with wind patterns and the Earth's rotation to

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[1]To whom correspondence should be addressed. E-mail: laborde@cwr.uwa.edu.au.

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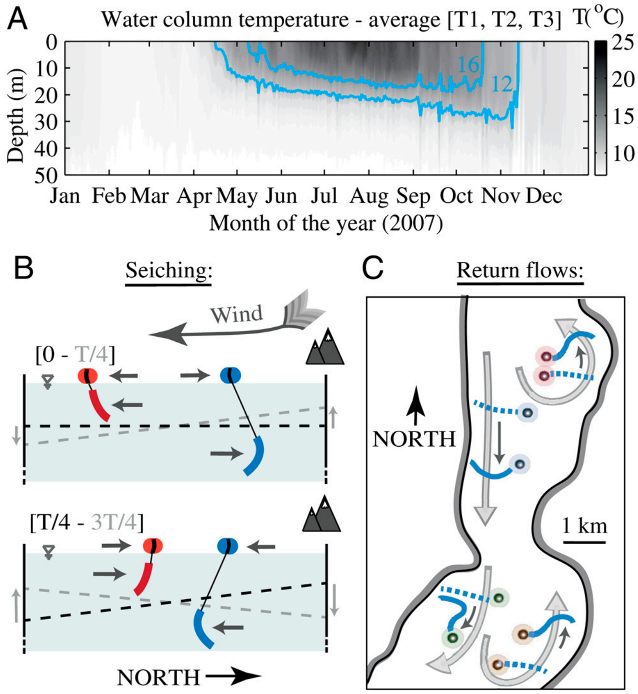

Fig. 1. Thermal structure of Lake Como and displacement of fishing nets due to internal motions. (*A*) The one-day moving average of water column temperature (shading) in Lake Como averaged across thermistor chains T1 (SW), T2 (N), and T3 (SE) throughout the year 2007; depth of isotherms 12 and 16 (blue lines) representing the preferred habitat of whitefish caught with oltane. (*B*) Schematic drawing (section view) of the displacements of two types of drift nets (pendenti for the capture of shad—red nets—and oltane for whitefish—blue nets), because of a wind-driven internal seiche (the dashed line represents the density interface—black at the lower time bound and gray at the upper time bound). *Top* and *Bottom* are separated in time by half the wave period. (*C*) Schematic drawing (map view) of the displacements of nets (oltane) due to gyres and return flows.

foster southward currents in the lake's metalimnion that tend to be stronger on the western side of the basin (10).

Small boat professional fishing is carried out in the lake by about 30 professional full-time fishers, for a total catch of about 200 ton of fish per year, of which the species of landlocked shad (agone) and whitefish (coregone) together represent between 75 and 80%. Throughout the stratified period (April to November), the shad is caught within the epilimnion whereas the whitefish, a salmonid, is found in the cooler waters of the lower metalimnion where the temperatures are within its preferred range of 12 to 16 °C (Fig. 1*A*). The capture of these species is carried out with large drifting gill nets (called pendenti and oltane), a common fishing technique requiring consideration of water motions throughout the upper 30 (in summer) to 50 m (in autumn) of the water column. The nets are set free at dusk, in the middle of the lake and perpendicular to the shores, constituting drifting barriers that may be 700 m long and 6.5 m (for the pendenti) to 9 m high (for the oltane). A weighted ground line (most often a lead cored rope) and an upper line tied to regularly distributed surface floats keep each net vertically extended: By adjusting the string length between the floats and the upper line, fishers can target different depths and thus different species of fish (refer to Fig. 1*B* for a schematic representation). The nets are attached to buoys and lights so they can be followed from shore during the night and located when the fisher comes to recover them, usually just before dawn. This routine is normally carried out nightly, with variations in targeted species throughout the year.

Fig. 1 *B* and *C* show the schematics of the nets' displacement in response to different types of internal motions in the lake: wind-induced seiches (*B*) and gyres and return flows (*C*). Understanding these motions is part of the fishers' work: Minimizing the distance to retrieve the nets is not as relevant as it was before most boats were equipped with engines (about 40 y ago), however the need to avoid entanglement between nets that were set at different depths by neighbor fishers remains relevant.

Results

Fishermen's Knowledge of the Lake's Seasons and Dominant Currents. The fishermen's practical knowledge of (*i*) the depth of the seasonal thermocline and strength of the stratification (data in Fig. 1*A*), and (*ii*) the existence and period of wind-induced internal seiches (Fig. 1*B*) was expressed in the interviews in the form of limnological heuristics (Table 1) acquired through the practice of drift-net fishing. The depth of the seasonal stratification is a key variable for fishermen using oltane nets to catch whitefish, as this species inhabits the lower metalimnion during the stratified period. Fishermen start setting these nets at about 1.5 m deep in spring and progressively lower the top of the nets, reaching about 30 to 40 m in autumn (Table 1, Fig. 1*A*). The pendenti, set in the epilimnion to catch shad, were generally reported to travel the fastest and in the direction of the wind, opposite to the oltane, therefore with the risk of encounter and entanglement between the two types of nets (Fig. 1*B*).

The characteristics of the seasonal stratification and primary motions such as seiches may be reasonably well-described and predicted scientifically with theory (11) and few monitoring stations. These processes are documented in Lake Como (e.g., Fig. 1*A*) through three in-lake stations—one at the end of each of the lake's arms (Fig. 2*A*, black stars)—that have been recording water column temperature and meteorological variables since 2006. The fishermen do not consult these data; their accounts of internal motions (Table 1) corroborated the temperature records independently, building confidence in their practical expertise of the lake's hydrodynamics (12).

Observations of Net Drifting Paths and Cross-Shore Flow Patterns. The fishermen also described the consistent formation of gyres and return flows in some areas of the basin (quotes Table 1, Fig. 1*C*). These qualitative accounts were interesting from the perspective of physical limnology, because such features (*i*) are highly relevant to the horizontal distribution of catchment material, thus to the lake's ecology; and (*ii*) require sampling at high spatial resolution to be documented quantitatively. One possible approach to document these flow features in the field is to use physical drifters, which, in essence, are what the fishing nets were, with the advantage of being very large and flexible, and to be reset and followed every night in most areas of the lake.

Fig. 2*A* shows a qualitative composite of all individual maps produced during interviews for the zone in which each individual fisherman generally said to operate with the oltane. The blue arrows indicate the dominant direction of the water currents as inferred from the paths reported as being most frequently followed by the nets overnight (from sunset to sunrise) in stratified conditions (late spring, summer, autumn) when the nets are set in the lower metalimnion. This map is only partially valid for common meteorological conditions meaning the alternation of a Tivano (light northerly wind) in the morning and a moderate Breva (medium southerly wind) in the afternoon, and the absence of storm winds, especially the Vento (strong northerly wind) that changes circulation patterns by inducing large-amplitude seiching (Fig. 1*B*).

Most fishermen highlighted that one could never be sure the nets would follow the patterns indicated as most likely, even with the right wind conditions. Such uncertainty, which leads professional fishermen to regularly inspect the displacements of their drifting nets from the shore, was particularly associated with the areas of the centro lago and the Como arm. The fishermen interviewed expressed the velocity of nets relative to other zones, other periods, other depths, or other types of nets, and the

Table 1. Hydrodynamic processes and corresponding fishermen's heuristics or practices

Hydrodynamic process and relevant figure	Local knowledge data
Seasonal stratification	
Fig. 1*A*	When you fish for whitefish in April, you set [the top of the nets] at one arm span (spazza), because they have always been caught at one arm span, since the world is world. … After two months, you catch them at three arm spans, 3.5 even, and then further down and down … (alto lago)
Fig. 1 *A* and *B*	In summer, if we have nets near the surface or even in the first, say, 20 m, when there is a strong wind the nets travel far and fast; while in winter, even if there is a strong wind … the water runs less at the surface: The velocity of the current is smaller, and it doesn't last as long. (centro lago)
Fig. 1 *A* and *B*	If we set deep nets in August, September, or October, at say 60–70 m depth because the whitefish (bondella) starts going down to these depths, if there is a strong wind we retrieve clean nets, so it means that the wind hasn't moved the water that deep. If we happen to set [the nets] there in January or February they get full of leaves, of algae, so it means that the force of the wind has managed to reach down to these depths. (centro lago)
Vertical mode 1 internal seiche	
Fig. 1*B*	When at the surface [the lake] goes north (in su), underneath it goes south (in giù); when at the surface it goes south; underneath it goes north. (General rule stated by several fishermen interviewed)
Fig. 1*B*	In summer when there is a strong wind the water at the surface follows the wind first, and then it starts moving underneath too, in the other direction. (centro lago)
Fig. 1*B*	When there is the northerly [wind] for a day, the first night the undercurrent always goes north very fast. Then if you get 3 d of wind, the second night it goes south very fast. (alto lago)
	Yes … it's like this. But if you set nets near the surface it's the other way around. And … say there's a week of wind, when the wind stops, the lake keeps going. (Other fisherman from alto lago, joint interview)
Transversal variability in flow patterns	
Fig. 1*C*, Fig. 2*B*, *i*	If I put the nets on the [western] shore of Dongo, or Cremia when there is the Adda, the nets tend to take the current and go [south] toward the Como or Lecco arms. In general they arrive near Bellano and then they turn around. If I set them on our [eastern] side here, they tend to go up north. (alto lago)
Fig. 2*B*, *v*	What can happen is that over here [the current] goes faster, from the middle to there, it goes less, therefore, the net that is set perpendicular to the shore is found rotated in the morning. (Lecco arm)
Fig. 2*B*, *ii*	This point blocks the current … one thing we may do if we don't want the nets to travel too far is to set, say, half the net inside [behind] the point, so that half is stalled while the other half catches the current and it rotates it like this. In the end the current drags [the net] away, but you've saved time. (centro lago, Como arm)
Fig. 2*B*, *v*	[The lake] turns underneath, does a swirl. It comes [south], turns like this and comes back north on this shore. This is true at the depth of the oltane. If there are two sets of nets for the whitefish near each other and they go south, they might end up way down [south], but one or both may also turn in this embayment and come back toward north, and then turn again and go back toward south. … So they may end up more or less where they were set, but in the reverse order! … [It is] because there are the points on the shores where the river has made a promontory by filling up the lake, this causes a vortex. (Lecco arm)

Local knowledge data consists of direct quotes from interviews with fishermen of the lake, translated by S.L.

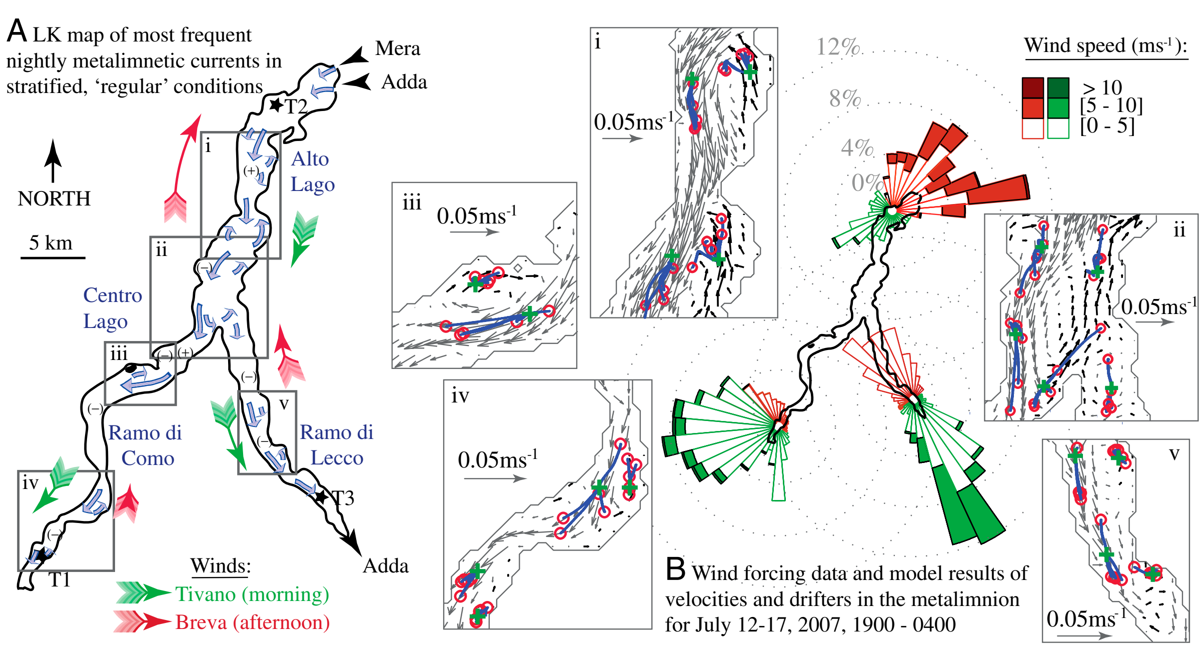

Fig. 2. Comparison of qualitative map and model results of nightly patterns of metalimnetic motions. (*A*) Qualitative map of water currents inferred by the displacements of oltane nets, overnight, during the stratified period and in common wind conditions (daily alternation of Tivano and Breva). Composite of individual maps obtained from interviews and participatory mapping with 22 professional fishermen. (*B*) Records of wind speed and direction at stations T2 (N), T3 (SE), and T1 (SW) for July 12-17, 2007; green and red shadings pertain to Tivano (northerly) and Breva (southerly) winds. (*Insets*) Model results of velocities in the metalimnion for July 12–17, 2007, output every 0.5 m (depth) and 15 min (time), then averaged overnight (1900–0400 hours) and depth (12–21 m). Return flows are highlighted in black. Blue lines are nightly (1900–0400 hours) paths of constant-depth numerical sail drifters (one path per night between July 12–17) set in the lower metalimnion (12–21 m). Each green cross is the start of a path, each red circle its end. Frame locations are in *A*.

Table 2. Set of model performance statistics proposed in ref. 14 comparing model output and data at T1 (15 depths), T2 (13 depths), and T3 (8 depths)

	T1	T2	T3
N	355,272	406,529	203,614
MAE (°C)	0.8244	0.7702	1.0865
RMSE (°C)	1.2043	1.0714	1.4779
d_2 [0 − 1]	0.9825	0.9859	0.9693

distance traveled by the nets varied each night, thus the length of the arrows on the map does not reflect quantitative differences in velocity. The large-scale velocity patterns that were recurrent in the narratives of fishermen familiar with several zones of the lake do however appear on the map: The strongest currents were said to be in alto lago and centro lago as well as the northern part of the Como arm [Fig. 2*A* (+)], whereas the southern part of the Como arm and the Lecco arm were generally described as less prone to strong water currents [Fig. 2*A* (−)] except after a strong northerly wind, which reportedly sets the whole lake in motion. Fishers from different zones of the lake also emphasized the relevance of different forcings on the flow patterns: Those who fished in the north (alto lago) stressed the role of the large inflows (Adda and Mera, Fig. 2*A*), those in the southwestern arm (ramo di Como, the closed arm) that of the storm winds, and those of the southeastern arm (ramo di Lecco) that of the outflow regime that is dam-regulated at the southeastern end of the lake.

Modeling Results. The practical observations by the fishermen of transversal variability in the water flows (Table 1, Fig. 1*C*, Fig. 2*A*) lead to a numerical modeling study to verify and further describe the formation of these features. Fig. 2*B*, *Insets* display the results of a numerical, three-dimensional hydrodynamic simulation of the lake for comparison with the qualitative map (Fig. 2*A*; see *Materials and Methods*). The velocities were output at depths corresponding to temperatures ranging between 12 and 16 °C, where the whitefish are found at night and the oltane are normally set. Simulated velocities were averaged overnight between 1900 and 0400 hours, corresponding to typical net setting and retrieving times, for a period in summer (July 12–17) that was chosen for regular wind conditions corresponding to a common pattern of moderate northerly wind in the morning and southerly in the afternoon (Fig. 2*B*). Also, the summer stratification was strong and the inflows to, and outflow from, the lake were high at this period (because of snowmelt) so pronounced current patterns were expected.

Most of the flow features computed by the model (Fig. 2*B*) corroborated descriptions by the fishers (Table 1, Fig. 2*A*). The black velocity arrows highlight the presence of velocities opposing the main current in coves and embayments (Fig. 2*B*, *i*, *iii*, *iv*, and *v*), or caused by larger scale features such as gyres in the widest zones of the lake (Fig. 2*B*, *ii*). The blue tracks show the paths of numerical drifters that were set to provide nightly drifting trajectories comparable with the qualitative flow paths inferred from the trajectories of the drifting oltane nets (see *Materials and Methods* for a description of the numerical drifters). These results evidenced patterns in the drifting paths night after night, as well as the relative variability from one night to another.

The main north-south flow path in the lower metalimnion was a result of wind forcing, combined in the north with inflow intrusions and in the southeast with the effect of the proximity of the outflow. Most return flows reflected the pressure gradients caused by the winding bathymetry, which was the element generally cited by fishermen to explain the return flows and gyres (e.g., Table 1). The Earth's rotation also played a role in the west-east variability of the flow by causing stronger velocities along the western shore of the lake, and in the formation of the large features (gyres) in the widest parts of the basin (alto lago and centro lago, Fig. 2*B*, *i* and *ii*) where the internal Rossby radius of deformation calculated for July 12–17 was comparable to the basin width (~3.5–4 km).

Discussion

The local knowledge of Lake Como's fishermen about flow patterns in the lake was considered through the lens of physical limnology, and the extent of their practical limnology was an interesting finding in itself. From a methodological perspective, the fishers' descriptions of mesoscale cross-shore current patterns at depths where they set nets for whitefish (lower metalimnion) were particularly relevant, as they provided qualitative information about flow features that were not evidenced in temperature data records. These accounts elicited our interest and focused a numerical modeling study that confirmed the occurrence and form of the gyres and return flows described by the fishermen.

Further work may be conducted to parse in more detail the formation of each of the flow features described by the fishers and the model (Fig. 2, *Insets*) in terms of the relative contribution of wind-driven internal waves, inflows, the bathymetry of the basin, and the Earth's rotation. Such research could involve the design of a field experiment focused on zones of the lake identified as relevant by LK accounts and modeling results. Our point here is that qualitative data from local knowledge accounts, combined with process-based numerical modeling, provided a solid anchor point to further the study of horizontal transport in the lake, particularly of mesoscale processes that may have been overlooked because of their spatial scale by a study solely based on quantitative data.

Scientific knowledge (SK) aims to explain and predict natural phenomena. Local practical knowledge emerges from the adaptation of people's life and work to natural phenomena through their lifestyle, history, sociality, and everyday practice. LK, therefore, like SK, gets to know natural environments. This article does not suggest that LK can substitute scientific research or provide insights that can be readily integrated to science, or that it should or can always be integrated into scientific research projects. We argue, however, that exposure to LK can foster and complement environmental science by providing a long-term, situated perspective on processes occurring in natural systems, which are the field sites of environmental scientists and the sites of everyday life for LK holders. In so doing, such an approach can assist environmental scientists in framing hypotheses and designing focused experiments, with the ultimate aim to produce SK that is verifiable through standard scientific procedures and easily transferable. We conclude that, when relevant and possible, the intellectual engagement of scientists with other knowledge groups such as LK holders can result in a more comprehensive scientific understanding of geophysical systems such as lakes.

Materials and Methods

Qualitative data documenting the fishermen's LK of the lake hydrodynamics were collected using social science research methods. The first author conducted a 3 mo period of ethnographic field work in summer–autumn 2010 that involved participant observation of the fishermen's practices on and off the boat, in-depth interviewing, and participatory mapping with 22 professional fishermen whereby patterns of net paths were drawn by the researcher and/or the interviewed fisherman on an outline of the zone of the lake relevant to the fishing practice. The interviews were then transcribed and analyzed, and the maps were reexamined in light of the corresponding interview and digitized. The research was approved by the Human Research Ethics Committee of the University of Western Australia, and informed consent was obtained from all participants.

The fishers were approached with some a priori knowledge of the lake's hydrodynamics, which helped to identify the connections between local and scientific knowledge, particularly through the fishers' accounts of well-known primary processes and the potential scientific interest of other narratives relating to locally unexplored processes such as the transversal variability of flow patterns. We suggest that such prior knowledge is an important point for studies that aim to integrate SK and LK: One reads local accounts differently in light of scientific results, and the other way around. Therefore, making the most of interactions with LK holders requires a form of dialogue between qualitative and quantitative information.

The physical data included wind speed and direction as well as water column temperature from the water surface to a depth of 150 m, recorded by thermistor chains at three in-lake stations located at the end of each arm of the lake (Fig. 2*A*, black stars). The temporal resolution was 20 s and the vertical resolution of temperature sensors along the chains ranged from 0.25 m near the surface to 20 m in the deep hypolimnion, allowing a long-term, fine-resolution documentation of the lake's thermal structure. Relative humidity, air temperature, short-wave radiation, and net radiation were measured at the northern station, whereas rainfall was obtained through the regional Agency for Environmental Protection (ARPA Lombardia), and inflows, outflows and lake level data through the Consortium for the Adda River (Consorzio dell'Adda).

The lake's hydrodynamic model was produced using the finite difference Estuary Lake and Coastal Ocean Model (ELCOM) that solves the Reynolds-averaged Navier–Stokes equations and scalar-transport equations with the hydrostatic and Boussinesq approximations (13). The three-dimensional grid of the lake-domain had a horizontal resolution of 200 m and a vertical resolution ranging from 0.5 to 86 m, with the finest resolution from the surface down to 20 m and a regular increase to the coarsest resolution in the deep hypolimnion. The model was initialized with a mean temperature profile for January 1, 2007, at 0000 hours and ran for the full year of 2007 with a time step of 1 min, solely forced with atmospheric and water fluxes data. The 1-y simulation was to assess the model's capability to reproduce seasonal variations as well as phenomena occurring over a few hours such as internal waves, because the qualitative data covered these various timescales. The reasons for choosing 2007 pertained to data availability. The performance of the model was evaluated by calculating the set of statistics proposed by Willmott (14)—mean absolute error (MAE), root mean square error (RMSE), and index model performance (d_2, should approach unity)—for the water column temperature records from the three thermistor chains over the whole year (Table 2). The data matrix was subsampled every 15 min to match the model output time series and the model values were linearly interpolated onto the measurement depths after correction for variations in water level. Data points deeper than 50 m were removed to avoid enhancing model performance measures with data from the hypolimnion, which sees very little temperature change over the year and was not relevant to the analysis carried out in this article.

After validation, numerical results were extracted for comparison with the fishermen's accounts. The results presented in Fig. 2*B*, *Insets* were velocities averaged between 12 and 21 m depth, corresponding to temperatures ranging between 12 and 16 °C for a period ranging from July 12–16, 2007, a period chosen for its regular and moderate wind forcing (Fig. 2*B*), strong stratification (Fig. 1*A*), and relatively high inflows and outflow—conditions that we hoped would evidence the flow patterns described by the fishermen. The temperature/depth range corresponds to the lower metalimnion at this period, where the whitefish were found and the oltane nets were set. Net depths in arm spans extracted from the interviews confirmed these depths. Velocities were averaged overnight between 1900 and 0400 hours, corresponding to typical net setting and retrieving times.

To make a qualitative comparison with the flow paths described by the fishermen, the trajectories of numerical drifters were also simulated using the available algorithms in ELCOM for semilagrangian, fixed-depth sail drifters (15). The drifters were rectangular stiff sails 9 m high and 200 m wide, with total weight and drag coefficient set to 30 kg and 0.5, respectively. The sails were stretching between a 12 and 21 m depth (like the oltane nets), and released at the same location every night at 1900 hours and retrieved the following morning at 0400 hours. The model calculated the drag force on the drifters using the velocities at the relevant depths (12 to 21 m) at the location of the drifter's horizontal centroid at each time step. The drifters' width was that of one grid cell, the weight was an estimate based on fieldwork with the fishermen, and the drag coefficient (c_d) was within the range obtained from empirical equations for netting (16).

The cumulative distances traveled by the drifters overnight were comparable to those reported for the nets in regular conditions (in the order of 1 km). Inertia had a limited influence on the drifters' motion, which was dominated by drag, so the trajectories were not sensitive to the drifters' weight. The paths of drifters with varying c_d displayed the same horizontal flow patterns and similar accumulated distances. Increasing c_d up to 2, which is very high even for much thicker netting than is considered here (16), led to increases in the distances traveled overnight by the drifters that were well within the range of uncertainty associated with the qualitative and relative nature of the fishermen's accounts of distances traveled by their nets. For example, doubling c_d to 1 led the drifters to travel an average increase of about 100 m overnight, and a c_d value of 2 led to an increase of about 150 m. For comparison, a variability of several hundred meters was associated with the fishermen's accounts of the average distances traveled by their nets in common weather conditions.

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