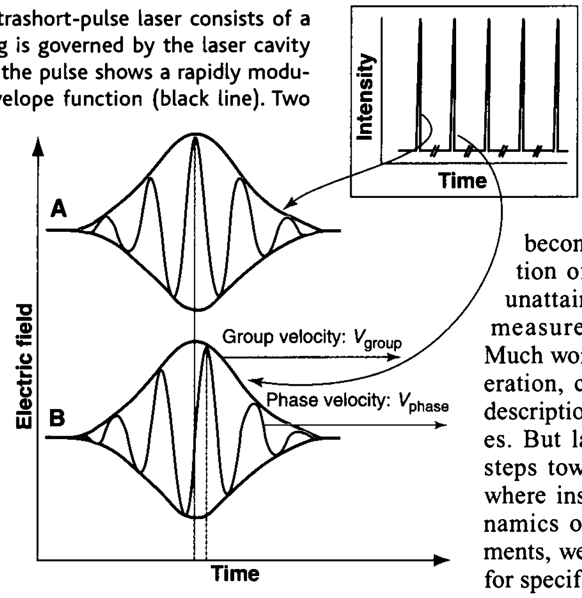

Ultrashort optical pulses. The output of an ultrashort-pulse laser consists of a stream of regularly spaced pulses whose spacing is governed by the laser cavity geometry (**inset**). More detailed examination of the pulse shows a rapidly modulating carrier field (red line) and an overall envelope function (black line). Two pulses emitted by the laser need not have the same carrier phase despite having an identical envelope function. This is illustrated by the difference in the position of the peak of the carrier amplitudes between pulses A and B and is caused by the difference between the group velocity V_{group} and phase velocity V_{phase} of the pulse. The drop lines are provided as a guide to the eye. To achieve coherent combination of pulses, the pulses must be not only synchronized in time, but their carrier phase must also be fixed through active control of the laser cavity.

field carrier underlying the pulse envelope (*3*). At such short pulse durations, the behavior of the carrier has substantial effects on both individual pulses and the train of pulses as a whole (see the figure).

In the general case, the speed of the pulse envelope or group velocity, V_{group}, and the speed of the underlying carrier wave, $V_{carrier}$, are not the same. As a result, there may be a carrier phase difference between pulses from oscillators (see the figure). This process undermines the possibility of producing a combination of the two pulses that remains coherent.

Much recent work has focused on controlling the carrier phase (*4–8*). Techniques for locking the carrier phase of individual pulses have been developed. Locking the carrier phase results in a stream of truly uniform optical pulses that are identical in all respects to one another. A central goal of this work has been the generation of ultrastable optical frequency combs to provide new levels of accuracy in optical frequency–based spectroscopy and high-precision metrology (*8–10*).

By successfully combining the output from two oscillators to produce a bandwidth of coherent light pulses that is greater than that available from a single laser, Shelton *et al.* have advanced one step toward the fabrication of designer-made light pulses for use in applications ranging from the coherent control of dynamical processes to the ultraprecise measurement of optical frequency standards. Two criteria must be fulfilled in their experiments: The repetition rate of the two lasers combined in their experiments must be controlled precisely to ensure that the laser pulses are emitted at the same time from each oscillator, and the phase within the pulses generated in each system has to be locked. Only when these variables are adequately controlled for each laser oscillator can the two separate coherent pulses be synchronized with respect to one another. When combined, these two pulses may therefore be viewed as a single pulse. Provided that the lasers are operating at different center wavelengths, the "superpulse" thus produced has a broader range of wavelengths than either of the two individual pulses. The duration of an optical pulse is inversely proportional to its bandwidth, and the composite pulse should therefore be shorter than either of the input pulses. Shelton *et al.* indeed deduced this from their experimental observations.

Ultrashort-pulse lasers are beginning to provide access to a fascinating regime where we can better understand and control the foundations of light. With such techniques, it may become possible to control the evolution of pulses and provide previously unattainable levels of accuracy in the measurement of optical frequencies. Much work remains to be done in the generation, characterization, and theoretical description of extremely short light pulses. But laser scientists are making first steps toward creating "designer pulses" where instead of letting the intrinsic dynamics of the pulse control our experiments, we can tailor the pulses we require for specific applications.

References

1. R. K. Shelton *et al., Science* **293**, 1286 (2001).
2. J. M. Hopkins *et al., Sci. Am.* **54**, 72 (September 2000).
3. U. Morgner *et al., Opt. Lett.* **24**, 411 (1999).
4. H. R. Telle *et al., Appl. Phys. B* **69**, 327 (1999).
5. D. J. Jones *et al., Science* **288**, 635 (2000).
6. A. Poppe *et al., Appl. Phys. B* **72**, 373 (2001).
7. U. Morgner *et al., Phys. Rev. Lett.* **86**, 5462 (2001).
8. Th. Udem *et al., Phys. Rev. Lett.* **82**, 3568 (1999).
9. S. A. Diddams *et al., Optics & Photonics News* (October 2000), pp. 16–22.
10. J. Stenger *et al., Phys. Rev. A* **63**, 021802 (2001).

PERSPECTIVES: ECOLOGY AND CONSERVATION

Whose Fish Are They Anyway?

John J. Magnuson, Carl Safina, Michael P. Sissenwine

The bluefin tuna has inspired art and literature, driven sport and commercial fisheries, and been the object of scientific debate, catch and allocation negotiations, and even fist fights (*1*). Weighing as much as 700 kg and often sighted at the ocean surface, they are valued above all other fish species for sushi and sashimi—one 200-kg bluefin recently sold at auction in Japan for a record \$390 per pound (*2*).

Atlantic bluefin tuna have been the subject of one of the most controversial fishery management sagas ever. At the core of the controversy is the dramatic decline in the abundance of the western Atlantic bluefin since the 1970s (see the figure) and the question of "whose fish are they?" The decline in the western Atlantic bluefin has intensified the question of "who gets the fish?" The U.S. fishing industries (both recreational and commercial) have argued that assessments of the western Atlantic bluefin population would be more optimistic if their movements between the western and eastern Atlantic were taken into account. They also have argued that they are being penalized for overfishing of bluefin by fishermen in the central and eastern Atlantic, including the Mediterranean Sea. A 1994 National Research Council (NRC) report on the western Atlantic bluefin population concluded that the trans-Atlantic movements or "mixing" of bluefin tuna needed to be taken into account, but that it would be impossible to do this reliably without better data (*3*).

In their elegant study on page 1310 of this issue, Block *et al.* (*4*) now provide valuable information on the migratory and diving behavior of the free-ranging bluefin

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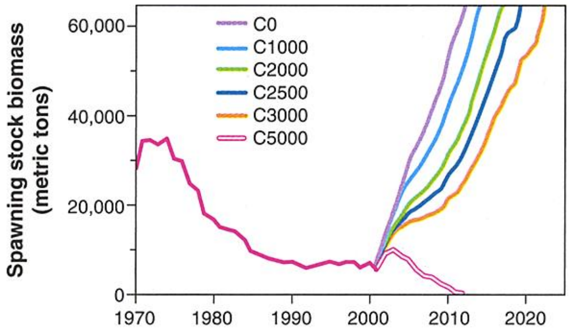
and the environmental conditions it encounters on its travels. These investigators commandeered two new types of electronic tag to track the movements of fish and to collect physiological and oceanographic information. Pop-up satellite tags download data to a computer via satellite once they are released from the fish (about 6 weeks after attachment) and "pop up" to the ocean surface. Archival tags, which are implanted in the fish, continue to record data until the fish is recaptured and the tag is recovered.

From both sets of data, Block *et al.* conclude that bluefin migratory behavior is very complex. They describe four types of migratory behavior: western Atlantic residency without visiting a known spawning ground, western Atlantic residency including a visit to a known spawning ground, trans-Atlantic movement from west to east and back, and trans-Atlantic movement to the east after 1 to 3 years of residency in the west. They also found that bluefin tuna maintain a rather stable core temperature of about 26°C, even though these fish routinely dive from warm surface waters of 30°C to deep cold waters as low as 3°C. Maintaining a high and stable body temperature may enhance the power output of their muscles, enabling the tuna to swim rapidly. Perhaps Block *et al.*'s most important finding is that western and eastern populations of bluefin "mix" to a far greater degree than previously thought. The controversy over who owns the bluefin tuna is international because the species is distributed throughout the North Atlantic and is fished by many countries. Block *et al.*'s main finding—that western Atlantic fish mix with their eastern relatives far more than predicted by conventional tagging methods (*5*)—will spark further debate over management of the Atlantic bluefin.

The International Commission for the Conservation of Atlantic Tunas (ICCAT) manages the Atlantic bluefin tuna as two separate management units (eastern and western Atlantic). Even though conventional tagging shows some trans-Atlantic mixing, this split in management reflects the fact that there are two geographically distant spawning areas (Gulf of Mexico and Mediterranean) and that eastern and western fish have different ages and sizes at maturity. Unfortunately, the 1994 NRC report was widely misinterpreted as indicating that inclusion of mixing in the stock assessment would show that the western Atlantic population was in better condition than if mixing was not included in the assessment. In fact, including mixing in the NRC's stock assessment indicated that the number of bluefin produced in the west was much lower than that predicted by ICCAT's assessment (*5*). There have been several more recent attempts to estimate mixing rates from conventional tagging data and to account for mixing in stock assessment models. The results, however, have been deemed too unreliable to serve as a direct quantitative basis for ICCAT management decisions, but have prompted ICCAT science advisors to repeatedly warn that bluefin populations in the eastern and western Atlantic are interdependent, and that overfishing in the eastern Atlantic jeopardizes recovery of bluefin in the western Atlantic.



Rebuilding the bluefin. Spawning stock biomass estimates of western Atlantic bluefin tuna, and projections of future biomass based on six levels of constant annual catch (C) in metric tons. In 1982, ICCAT began setting an annual catch limit in an effort to end overfishing and to conserve the spawning biomass. It took nearly another decade before the biomass stabilized at about 20% of the level during the 1970s (pink line). The projections indicate the potential for rapid rebuilding of the western bluefin population in the future. On the basis of these projections, ICCAT scientific advisors recommended that the catch be maintained at its current level of about 2500 metric tons (dark blue line). [Modified from ICCAT's "2000 Atlantic Bluefin Tuna—Executive Summary" at www.iccat.org]

Block *et al.* conclude that there is mixing of tuna in western and eastern feeding grounds, but that the fish may separate for spawning in either the Gulf of Mexico or the Mediterranean. None of the tagged fish visited both known spawning grounds, although that possibility cannot be ruled out with the still relatively small numbers of fish observed. Genetic analyses have not demonstrated that spawners in the western and eastern Atlantic are reproductively isolated. This is not surprising because even low rates of genetic mixing can produce populations that are not genetically isolated. By analyzing the chemical composition of otoliths in the fish inner ear, scientists have been able to distinguish bluefin tuna from different regions of the Pacific (*6*). This approach is now being applied to the Atlantic bluefin and should help to determine the origin of fish caught in eastern, western, and central Atlantic fishing areas.

Lutcavage *et al.* (*7, 8*) have also applied electronic tagging techniques to study migrations of Atlantic bluefin. Their research indicates that about 30% of the fish tagged off the New England coast migrate across the mid-Atlantic into the eastern Atlantic management area. Also, mature-size bluefin in this tagged population generally migrate to the central Atlantic (Sargasso Sea) during the spawning season. This is an important finding because an increasing proportion of the total catch has been taken in the central Atlantic in recent years. These authors raise the possibility that there exists a third spawning ground in the central Atlantic.

Beginning in the early 1980s, ICCAT set an allowable catch for the western Atlantic at approximately half the total catch of the 1970s, with restrictions on catching smaller fish. Unfortunately, the spawning biomass continued to decline through the 1980s, before stabilizing during the 1990s at about 20% of the spawning biomass of the mid-1970s. Research data including those of Block *et al.* are consistent with ICCAT's most recent recommendation (*9*) to continue limiting the western Atlantic bluefin tuna catch to allow rebuilding of the population, and to end overfishing in the eastern Atlantic, which, owing to the migration of fish across the Atlantic, could jeopardize rebuilding in the west. Unfortunately, overfishing in the eastern Atlantic continues. Block *et al.*'s finding that there is greater mixing of eastern and western bluefin than previously thought provides additional evidence for the interdependence of fisheries on both sides of the Atlantic, and the need to halt overfishing in the eastern Atlantic.

References and Notes

1. C. Safina, *Song for the Blue Ocean* (Holt, New York, 1998).
2. Associated Press, "Giant tuna sells for record $173,600" (www.flmnh.ufl.edu/fish/InNews/GiantTuna.htm).
3. National Research Council, *An Assessment of Atlantic Bluefin Tuna* (National Academy Press, Washington, DC, 1994).
4. B. A. Block *et al.*, *Science* **293**, 1310 (2001).
5. M. P. Sissenwine, P. M. Mace, J. E. Scott, G. P. Scott, *Trans. Am. Fish. Soc.* **127**, 838 (1998).
6. J. Rooker, D. Secor, V. Zdanowicz, *Mar. Ecol. Prog. Ser.*, in press.
7. M. Lutcavage *et al.*, *Can. J. Fish. Aquat. Sci.* **56**, 173 (1999).
8. M. Lutcavage *et al.*, *Mar. Biol.* **137**, 347 (2000).
9. ICCAT, *Report of the ICCAT SCRS West Atlantic Bluefin Tuna Stock Assessment Session* (SCRS/00/24); Madrid, Spain, Sept. 2000 (available at www.iccat.org).