structure on $\boldsymbol{R}^4$, and further work by Donaldson implies that such an exotic structure resides as an open subset of ordinary $\boldsymbol{R}^4$.)

Differential geometers have long been aware that four-dimensional space does have some remarkable properties that distinguish it from spaces of other dimensions. In four-dimensional space the rotation group $SO(n)$ is a simple Lie group for all $n = 4$ and $SO(4)$ is locally isomorphic (double covers) $SO(3) \times SO(3)$. As the six-dimensional space $\Lambda^2(\boldsymbol{R}^4)$ of 2-forms on the inner product space $\boldsymbol{R}^4$ can be viewed as the Lie algebra of $SO(4)$, $\Lambda^2(\boldsymbol{R}^4)$ decomposes as the sum of the three-dimensional spaces $\Lambda^2(\boldsymbol{R}^4) = \Lambda^2{}_+ \oplus \Lambda^2{}_-$. This decomposition is significant in Riemannian geometry, for if a 4-manifold M admits a Riemannian metric and P is a principal $SU(2)$ bundle over M, a connection ($SU(2)$-gauge potential) ∇ in P has a curvature (gauge field) R^∇, which is a 2-form (with values in a Lie algebra). Thus R^∇ decomposes as $R^\nabla{}_+ + R^\nabla{}_-$. It is only in dimension four that the curvature decomposes. A connection whose curvature satisfies the equation $R^\nabla = R^\nabla{}_+$ ($R^\nabla{}_-$) is called self-dual (anti–self-dual). Such solutions minimize the Yang-Mills functional (that is, they minimize the field strength) and are sometimes referred to as instantons.

Physicists have also long been aware of the special nature of four-dimensional space. Yang-Mills theory was developed by physicists to give a classical model of strong interactions, which because of their range are known to be quantum phenomena. It is quite remarkable that in the development of this theory many of the concepts of modern global differential geometry and topology, such as bundles, connections, curvature, and Chern-Weil theory of characteristic classes were reinvented by physicists. After acceptance of the relevance of non-Abelian gauge theories—that is, bundles with structure groups more interesting than $U(1)$—it was recognized that Yang-Mills theory gave a renormalizable theory of the coupling of electromagnetic and weak interactions. The focus became the understanding of these minimal solutions on the special manifolds $\boldsymbol{R}^4$ or $\boldsymbol{S}^4$. This description was made possible by concurrent developments concerning stable vector bundles on complex projective 3-space that were made possible by an innovative tool, the Penrose twistor construction adapted to this theory by Richard Ward. The work of Atiyah, Hitchin, and Singer, Atiyah and Bott, and Atiyah and Jones began to place this work in a more differential geometric context. Very recently solutions to the Yang-Mills equations over more complicated manifolds were obtained by Taubes, who utilized a strong implicit function theorem technique and the preliminary work of Uhlenbeck. The situation took a 180-degree turn when Donaldson made the space of these minimal solutions of inherent mathematical interest and showed that it contains information concerning the topology of the manifold over which the solutions were defined. After being mainly motivated by the questions of physicists, Donaldson showed that Yang-Mills theory can be utilized as a powerful tool to solve mathematical problems.

This book is designed for a mature mathematical audience with some background in topology and geometry. It presents Donaldson's work together with the foundational work in gauge field theory done by Uhlenbeck, Taubes, Atiyah, Hitchin, Singer, and others upon which Donaldson's arguments are based. The book is filled with insightful remarks, proofs, and contributions that have never before appeared in print. For anyone attempting to understand the work of Donaldson and the applications of gauge theories to four-dimensional topology, the book is a must. Although not for the weak at heart, the volume will pry open the door to the mathematical aspects of Yang-Mills theory. The door is just ajar. The field is extremely active, and the times are exciting. Donaldson has handed the topologists a tool that has applications that are still being discovered. The frontiers of four-dimensional topology—what a breathtaking place to be!

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Mate Choice

The Túngara Frog. A Study in Sexual Selection and Communication. MICHAEL J. RYAN. University of Chicago Press, Chicago, 1985. xvi, 230 pp., illus. $33; paper, $14.95.

The idea of Darwin's that met with most skepticism among other biologists was his theory of sexual selection, in particular the suggestion that conspicuous male "adornments" and behavior patterns may have evolved because females prefer highly adorned or active males as mates. This idea was opposed by most of Darwin's colleagues, including Wallace, partly because it seemed to require too much of an aesthetic sense in female animals.

For about a century, except for laboratory studies of *Drosophila* showing that females sometimes discriminate among males, not much happened in the way of testing Darwin's suggestion. Finally, sexual selection has become a subject of realistic field studies, following recent advances in quantitative recording, experimentation, and statistical analysis of animal behavior. This progress has coincided with an upsurge of interest and theoretical development in behavioral ecology and population biology, relevant for the understanding of sexual selection. As a result, there are now a number of field projects that address Darwin's theory.

Michael Ryan's clear, well-written book presents a particularly fine example. Its hero, the túngara frog, *Physalaemus pustulosus*, offers unique possibilities for testing crucial aspects of sexual selection theory. This is partly because the advertisement call of the male, in contrast with the simple calls of most other anurans, consists of two different components: *whines* and *chucks*. Ryan's study at Barro Colorado Island in Panama centers on the function and evolution of these two components, but it also deals with other aspects of reproductive behavior in an integrated fashion, combining approaches from several disciplines. The study demonstrates the remarkable explanatory power of field observations combined with incisive, controlled experiments and comparative analyses; it provides broad understanding of the species' biology as well as detailed answers concerning selective mechanisms.

Female túngara frogs often appear to sample several calling males before making contact with one of them; the male then clasps the female, and the pair goes off to mate and deposit the eggs in a floating nest, a sort of protective meringue house that the male builds by beating the jelly matrix of the eggs into foam. As the calling male does not defend any resource of importance to the female, she seems to choose her mate on the basis of his own characteristics.

What, then, makes for male mating success? The best predictor of a male's success is the number of nights he spends at the pond. The causes behind variation among males in this respect are not known; differences in their ability to procure surplus energy for spending time at the pond is one possible but untested reason.

In addition, male mating success increases with body size; it is here that the advertisement call comes in. Experiments by Ryan and Stanley Rand showed that the whine component is important for species recognition; females do not approach a speaker broadcasting only chucks. They are more attracted by calls containing both whine and chuck than by whines alone. Ryan suggests this is because females can better judge the size of the male from the chuck than the whine; females tend to approach chucks with low fundamental frequency, typical of

large males. The proportion of eggs fertilized is highest if the male matches the female in size. As most breeding females are larger than males, most females should benefit from choosing a larger than average male.

Why do males not always include the chuck, which should increase their attractiveness to females? Two decades ago, Rand began to suspect that male túngara frogs are threatened by some predator that uses the chuck to locate them. He based his suggestion on a comparison with the structure of alarm and mobbing calls of certain birds. Rand ventured this prediction although no predators were known to orient to frog calls.

This conjecture has now been confirmed to an astonishing degree through the work of Ryan, Rand, Merlin Tuttle, and their colleagues. Whodunit? A frog-eating bat, *Trachops cirrhosus*, turned out to be a major predator of the males (see the cover of *Science*, no. 4521, 1981)—another reminder for anyone who might still think of evolutionary biology as an entirely historical and nonpredictive science. Observations and playback experiments showed that the bat is attracted more by calls containing whine plus chuck than by whines alone, perhaps because chucks are more easily located as Rand suggested. At any rate, predation by bats seems to explain why males do not always include the chuck in their calls. This example provides a nice corroboration of the Darwin-Fisher idea that sexual selection for a trait may be opposed by counteracting natural selection, leading to a balance between the two.

While presenting an exemplary study of sexual selection in a natural population, this book also shows the difficulties of such an approach. Ryan is the first to admit that the evidence often does not permit a clear separation between alternative explanations. For instance, although it seems that the chuck has evolved in part owing to sexual selection through female choice, it is not clear why the female preference itself has evolved. Four possibilities are: (i) the preference is an effect of properties of the female's auditory system that evolved for reasons unrelated to mate choice; (ii) it has evolved because it makes the female mate with males providing superior nongenetic benefits, improving her reproductive success; (iii) it makes the female mate with genetically superior males, giving her offspring heritable above-average survivorship; (iv) the sons of females showing the preference inherit the preferred trait and hence have higher than average mating success.

The data do not permit exclusion of any of these four alternatives. There is evidence that the preference for large males leads to a higher proportion of eggs fertilized. In addition, comparison with related species suggests that the chuck component has evolved under sexual selection for lowered fundamental frequency, perhaps owing to joint evolution of male call and female preference. Mechanisms (*ii*) and (*iv*) hence may have been involved, but the two others have not been excluded. The issue is not easily resolved; sexual selection will probably continue to offer challenging problems for years to come. Nevertheless, this book gives a stimulating account of some steps that have been taken and others that remain on the way toward understanding of the importance of sexual selection and its various mechanisms. As usual, there are points on which one might disagree with the analysis or interpretations, but on the whole this is a careful, creative, and informative study that is likely to become a classic of its kind.

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