Gene expression, central to life processes, is intrinsically a stochastic process involving low copy number of biomolecules. Our real-time assay allows probing of low copy number proteins in single live cells not accessible by current technologies. This approach, together with other emerging single-molecule techniques (35), will yield further insight into not only gene expression but also other fundamental biological processes.

References and Notes

1. F. Jacob, J. Monod, *Cold Spring Harbor Symp. Quant. Biol.* **26**, 193 (1961).
2. J. Beckwith, *Science* **156**, 597 (1967).
3. W. Gilbert, B. Muller-Hill, *Proc. Natl. Acad. Sci. U.S.A.* **58**, 2415 (1967).
4. M. Ptashne, A. Gann, *Genes and Signals* (Cold Spring Harbor Laboratory Press, Cold Spring Harbor, NY, 2002).
5. X. S. Xie, H. P. Lu, *J. Biol. Chem.* **274**, 15967 (1999).
6. C. Bustamante, Z. Bryant, S. Smith, *Nature* **421**, 423 (2003).
7. A. Ishijima, T. Yanagida, *Trends Biochem. Sci.* **26**, 438 (2001).
8. S. Weiss, *Science* **283**, 1676 (1999).
9. M. D. Wang et al., *Science* **282**, 902 (1998).
10. S. Blanchard, R. Gonzalez, H. Kim, S. Chu, J. Puglisi, *Nat. Struct. Mol. Biol.* **11**, 1008 (2004).
11. O. Berg, *J. Theor. Biol.* **71**, 587 (1978).
12. D. Rigney, *J. Theor. Biol.* **79**, 247 (1979).
13. J. Paulsson, *Nature* **427**, 415 (2004).
14. J. Paulsson, *Phys. Life Rev.* **2**, 157 (2005).
15. Y. Shav-Tal et al., *Science* **304**, 1797 (2004).
16. I. Golding, E. Cox, *Proc. Natl. Acad. Sci. U.S.A.* **101**, 11310 (2004).
17. N. Barkai, S. Leibler, *Nature* **403**, 267 (2000).
18. E. M. Ozbudak, M. Thattai, I. Kurtser, A. D. Grossman, A. van Oudenaarden, *Nat. Genet.* **31**, 69 (2002).
19. M. B. Elowitz, A. J. Levine, E. D. Siggia, P. S. Swain, *Science* **297**, 1183 (2002).
20. N. Rosenfeld, J. W. Young, U. Alon, P. S. Swain, M. B. Elowitz, *Science* **307**, 1962 (2005).
21. S. Ghaemmaghami et al., *Nature* **425**, 737 (2003).
22. P. Guptasarma, *Bioessays* **17**, 987 (1995).
23. Materials and methods are available as supporting material on *Science* Online.
24. R. J. Bongaerts, I. Hautefort, J. M. Sidebotham, J. C. Hinton, *Methods Enzymol.* **358**, 43 (2002).
25. R. Y. Tsien, *Annu. Rev. Biochem.* **67**, 509 (1998).
26. M. Chalfie, Y. Tu, G. Euskirchen, W. W. Ward, D. C. Prasher, *Science* **263**, 802 (1994).
27. T. Nagai et al., *Nat. Biotechnol.* **20**, 87 (2002).
28. P. H. Lommerse et al., *Biophys. J.* **86**, 609 (2004).
29. J. Deich, E. M. Judd, H. H. McAdams, W. E. Moerner, *Proc. Natl. Acad. Sci. U.S.A.* **101**, 15921 (2004).
30. S. L. Mowbray, M. O. J. Sandgren, *J. Struct. Biol.* **124**, 257 (1998).
31. K. Bondeson, A. Frostellkarlsson, L. Fagerstam, G. Magnusson, *Anal. Biochem.* **214**, 245 (1993).
32. W. Hsieh, P. Whitson, K. Matthews, R. Wells, *J. Biol. Chem.* **262**, 14583 (1987).
33. O. Yarchuk, N. Jacques, J. Guillerez, M. Dreyfus, *J. Mol. Biol.* **226**, 581 (1992).
34. H. H. McAdams, A. Arkin, *Proc. Natl. Acad. Sci. U.S.A.* **94**, 814 (1997).
35. L. Cai, N. Friedman, X. S. Xie, *Nature* **440**, 358 (2006).
36. We thank P. Choi, L. Cai, N. Friedman, J. Elf, L. Xun, and R. Losick for helpful discussions and critical reading of the manuscript, J. Hearn for technical assistance, and A. Miyawaki (RIKEN) for the generous gift of the *venus* gene. This work was supported by NIH Director's Pioneer Award program, a NIH R21 grant, and in part by U.S. Department of Energy, Office of Science, and Applied Biosystems' Exploratory Fund. J.Y. acknowledges a Genome-Related Research Award from Merck.

Late Colonization of Easter Island

Terry L. Hunt[1]* and Carl P. Lipo[2]

Easter Island (Rapa Nui) provides a model of human-induced environmental degradation. A reliable chronology is central to understanding the cultural, ecological, and demographic processes involved. Radiocarbon dates for the earliest stratigraphic layers at Anakena, Easter Island, and analysis of previous radiocarbon dates imply that the island was colonized late, about 1200 A.D. Substantial ecological impacts and major cultural investments in monumental architecture and statuary thus began soon after initial settlement.

With an empty landscape containing gigantic statues and other cultural achievements, Easter Island, or Rapa Nui, symbolizes an isolated civilization that once flourished but suffered ecological catastrophe. Central to understanding the cultural, ecological, and demographic processes that shaped Rapa Nui's prehistory is the establishment of a reliable chronology for the island. Here, we provide radiocarbon dates from deposits likely to represent the earliest occupation on the island and evaluate previous ^{14}C dates to show that Rapa Nui's prehistoric chronology is later than has been commonly assumed.

Early Polynesians colonized Fiji, Tonga, and Samoa in the central South Pacific about 2800 years ago. Accumulating evidence shows that continued expansion from Samoa-Tonga into eastern Polynesia (e.g., Cooks, Societies, Marquesas, and Hawaii) did not occur until after 800 A.D., although notably longer chronologies have been suggested and debated (1–3). Many eastern Polynesian sites once considered centuries older have been shown to be consistently younger (4, 5). For example, it is now thought that New Zealand was colonized after 1200 A.D., about 400 years after the date that has long been assumed (6). This date has been confirmed by radiocarbon dating of seeds gnawed by the Polynesian rat (*Rattus exulans*) (7), clear evidence of human presence because rats are commensal species.

Smith (8) obtained initial radiocarbon dates from Rapa Nui with the Norwegian expedition of Heyerdahl in the 1950s. His suite of 19 radiocarbon dates included one from a burn horizon at Poike Ditch of 400 A.D. [1570 ± 80 years before the present (yr B.P.), 384 to 664 calibrated (cal) A.D.]. Subsequent researchers cited the

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Table 1. Radiocarbon dates from recent excavations at the Anakena Dune site.

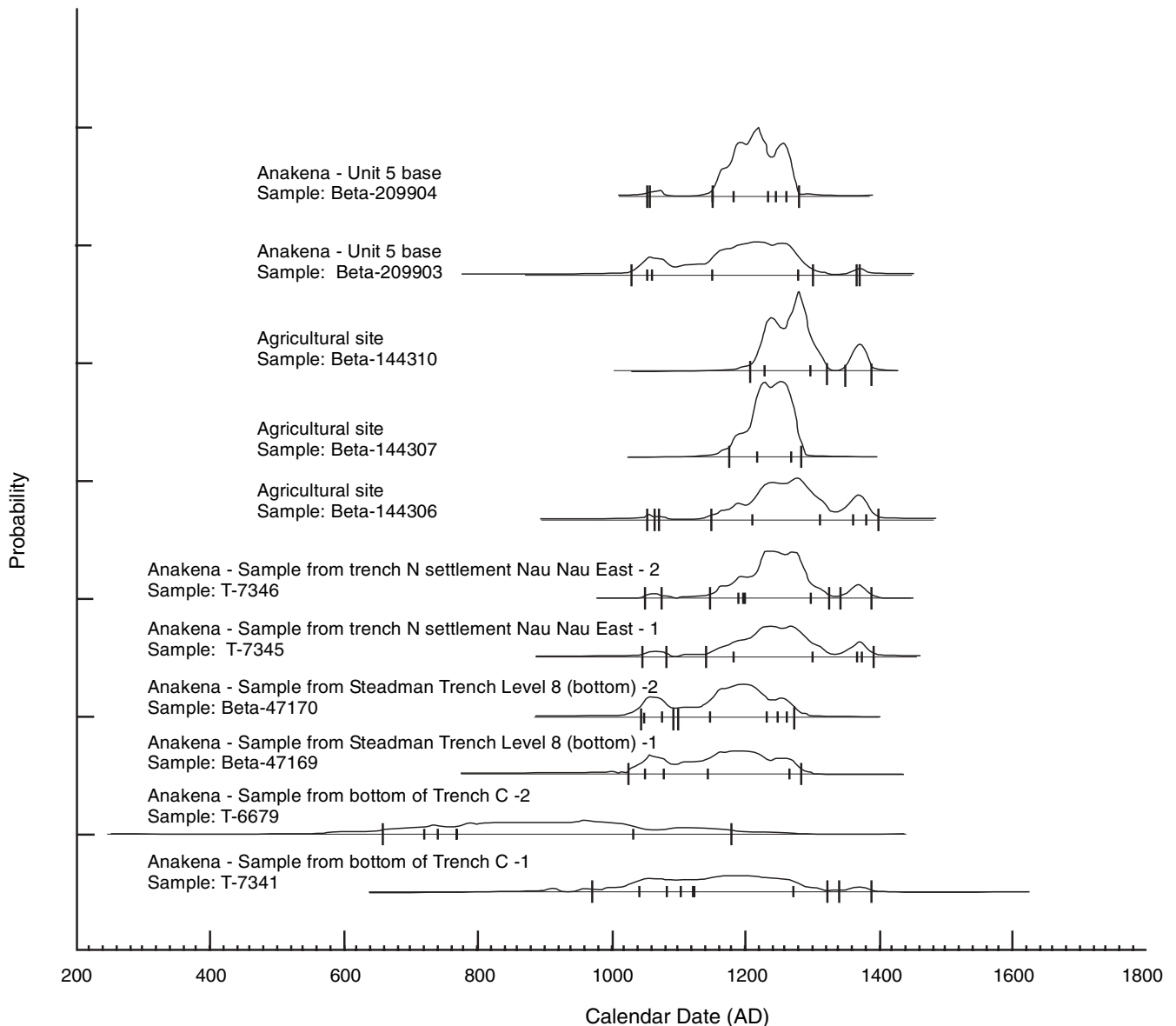| Sample Beta-	Material/layer	Radiocarbon age (yr B.P.)	^{13}C/^{12}C	Conventional C^{14} age (yr B.P.)	2σ calibration (cal A.D.) (19, 20)	Probability
196711	Charcoal/Unit 1 Layer 8	660 ± 40	−24.9	660 ± 40	1294–1403	1.00
196712	Charcoal/Unit 1 Layer 5	690 ± 60	−25.6	680 ± 60	1274–1414	1.00
196713	Charcoal/Unit 1 Layer 8	670 ± 40	−24.8	670 ± 60	1291–1400	1.00
196714	Charcoal/Unit 1 Layer 9	600 ± 60	−26.0	590 ± 60	1300–1368 / 1373–1450	0.369341 / 0.630659
196715	Charcoal/Unit 1 Layer 11	670 ± 40	−22.5	710 ± 40	1279–1391	1.00
196716	Charcoal/Unit 1 Layer 12	720 ± 60	−24.7	720 ± 60	1229–1251 / 1260–1400	0.046194 / 0.953806
209903	Charcoal/Unit 5 Base	870 ± 80	−23.8	870 ± 80	1029–1300 / 1368–1372	0.996544 / 0.003456
209904	Charcoal/Unit 5 Base	870 ± 40	−23.8	870 ± 40	1055–1058 / 1151–1278	0.003916 / 0.996084

Fig. 1. Probability distributions for 11 calibrated pre-750 yr B.P. dates that meet "chronometric hygiene" criteria from Rapa Nui; included are two new dates on wood charcoal from the base of recent excavations at the Anakena Dune site.

early date as consistent with models for historical linguistics in Polynesia (*9, 10*). Three dates on lake core sequences also provided, it seemed, evidence for an early colonization. The earliest signs of abrupt and massive vegetation change appeared to occur about 750 A.D. (*11*), suggesting the arrival of the first Polynesians. This long chronology has formed the basis of many accounts of the region's prehistory (*12*).

Recent studies have highlighted sources of error that may render radiocarbon chronologies from both archaeology and paleoenvironmental work erroneously old (*3*). Indeed, a recent analysis has shown the anomalous dating of bulk sediment samples from the lake cores of Rapa Nui (*13*). The lake core sediment dates reflect the continuous deposition of both old and young organic components, resulting in dates that are too old by hundreds of years (*14*). This makes

the present radiocarbon dates of bulk sediment from lake cores problematic, at least in terms of generating high-resolution paleoenvironmental reconstruction for Rapa Nui.

Recently questions have arisen about the long chronology. In an analysis compiling over 120 radiocarbon dates for the island, Martinsson-Wallin and Crockford (*15*) (table S1) rejected the early Poike date and questioned the validity of dates from 400 to 800 A.D. These authors concluded that dates before 800 A.D. were unreliable, but they accepted radiocarbon ages from 800 to 1200 A.D. and concluded that colonization dated to the beginning of that period (*15*).

Over the past two field seasons (2004 and 2005) on Rapa Nui, we excavated primary, in situ, and deeply stratified archaeological deposits at Anakena (figs. S1 to S6). Anakena is the island's only sand dune and provides a stratified

context of archaeological materials with superb preservation. In 2004 and 2005, we excavated an area of 14 m² containing 12 distinctive strata to a depth of more than 345 cm below surface (figs. S2 to S6 and table S2). The basal layer of these strata was clay substrate with an in situ primeval soil (paleosol) containing artifacts, charcoal, faunal remains (including *R. exulans*, introduced by Polynesians), and the distinctive tubular root molds of the giant, extinct *Jubaea* palm (also designated *Paschalococos disperta*). Below this horizon, the remaining stratum of clay was entirely devoid of cultural materials. Thus, the basal cultural layer preserves evidence of the initial human occupation at Anakena and, given the environmental context, probably the primary occupation for the island (*15, 16*).

Our excavations yielded faunal remains in quantities and composition comparable to the

Fig. 2. Aggregate (dashed line) and cumulative (solid line) probabilities for 11 calibrated pre-750 yr B.P. dates from Rapa Nui using CALIB 5.0 (*19*) and the southern hemisphere calibration curve, SHCal04 (*20*). The aggregate is the sum of probabilities at any particular point in time. The cumulative probability represents increasing confidence of dating the colonization event in the radiocarbon data set. A confidence of 0.50 is reached at 1222 cal A.D., suggesting colonization by this time. The tail permits earlier settlement (e.g., 1050 to 1150 A.D.), but the probability is very low based on the current radiocarbon record.
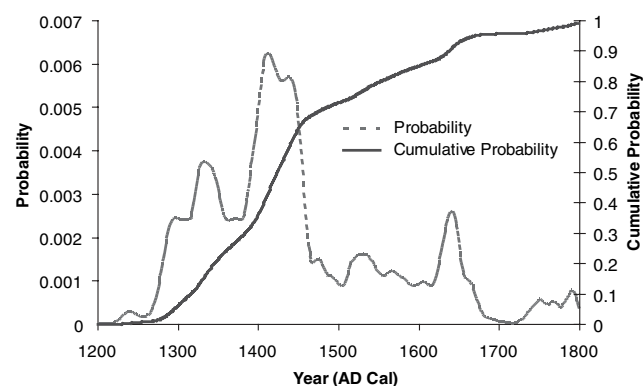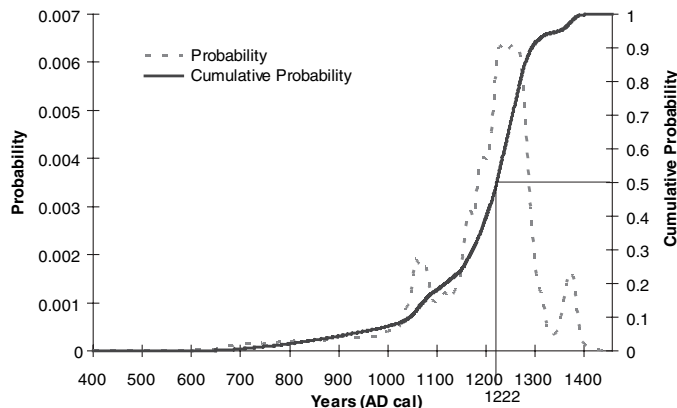

Fig. 3. Aggregate (dashed line) and cumulative (solid line) probabilities for 41 calibrated radiocarbon dates associated with extinct *Jubaea* palm remains and/or truncated primeval soils indicating human induced erosion. Note the post-1200 A.D. ranges for all dates and the steep rise after 1300 cal A.D. We compiled these dates from island-wide paleoenvironmental research reported by Mann *et al.* (*23*) and Mieth and Bork (*24*).

features" (*15*) (Fig. 1 and table S1). The calibrated probability distributions of these radiocarbon ranges (*19*, *20*) center around 1200 cal A.D. and all overlap at two standard deviations, with only a single determination (T-6679) yielding a long, flat calibrated range of low probabilities from 657 to 1180 cal A.D. (2σ).

The assemblage of 11 calibrated dates are age probabilities that, when aggregated, estimate a cumulative probability for the target event of the first human colonization of Rapa Nui (Fig. 2). The distribution shows that a 0.50 confidence, a better than chance estimation, is not reached until 1222 cal A.D. for the date of initial occupation of Rapa Nui. The error terms of these radiocarbon estimates permit earlier settlement; however, the chance in probability terms remains low. For example, the available dates show that a settlement event by 1050 A.D. has an aggregate probability of 0.0017 and a cumulative probability of only 0.24, i.e., possible, but less likely in the overall distribution. Additional radiocarbon dates will likely change the probability distribution and could reveal colonization of Rapa Nui sometime slightly earlier than 1200 A.D. (e.g., circa 1050 to 1150 A.D.).

These dates postdate by 700 to 800 (*12*) or at least 300 to 400 (*15*) years from the widely accepted human chronologies for Easter Island. Yet, a date of about 1200 A.D. for the colonization of Rapa Nui fits well with the evidence that has emerged for colonization from elsewhere in the southeastern Pacific (*4*, *5*), including remote islands such as Mangareva (*21*).

A late chronology challenges our understanding of the dramatic environmental changes that occurred on the island, highlighted by deforestation and concomitant erosion of primeval soils. We anticipate that given the effects of colonization, including introduction of the Polynesian rat, evidence of ecological change such as deforestation will closely mark the time of Polynesian arrival (*22*). Forty-one radiocarbon dates directly associated with deforestation from multiple sites around the island (*23*, *24*) (table S3) all fall after 1200 A.D., and most cluster after 1300 A.D. (Fig. 3). The long chronology (*23*, *24*) requires that Polynesian settlers had virtually no impact on the island's ecology and maintained an exceptionally low population growth rate for several centuries until a point of abrupt, dramatic human impacts. However, Polynesian "supertramp" populations expanded their numbers over the vast Pacific in a remarkably short time (*25*). Indeed, rapid population growth would be critical to successful colonization of remote islands. With even small numbers of initial colonizers (e.g., 50) at 3.0% growth rate (*26*), populations would rise dramatically and reach more than 2000 (a density of over 10 people per square kilometer on Rapa Nui) in just over 100 years.

Our analysis and dates for Rapa Nui imply that colonists arrived around 1200 A.D. The founding Polynesian population then grew rap-

well-known early assemblage excavated by Steadman *et al.* (*16*) at Anakena, where they reported 7311 specimens comprising (i) dolphin, (ii) rat, (iii) fish, (iv) bird, (v) pinniped, and (vi) human, in order of abundance. We recovered 6533 identifiable bones in which the *R. exulans* ranks first in quantity, followed by (ii) fish, (iii) sea mammals, (iv) bird, (v) human, (vi) "medium mammal" (i.e., likely sea mammal bone fragments and possible pinniped remains), and (vii) sea turtle. Both of the collections are notably different than later faunal assemblages from Rapa Nui that generally lack marine mammal resources.

To establish a chronology for the Anakena Dune strata, we obtained eight radiocarbon dates on wood charcoal samples (Table 1). We selected small wood charcoal specimens (i.e., from short-lived taxa) acquired from the same stratum or from directly superimposed strata. Pairing samples from stratigraphic contexts in this way allows for replication in radiocarbon assays. These radiocarbon results are consistent with stratigraphic superposition; they overlap in age at two standard deviations and document human occupation beginning about 1200 cal A.D. These late dates from Anakena led us to question the longer chronologies widely accepted for Rapa Nui.

Following primary criteria from the protocol established by Spriggs and Anderson (*4*, *6*) and

further developed among radiocarbon specialists (*17*), we compiled 45 published radiocarbon dates reported as older than 750 yr B.P. (uncalibrated radiocarbon years) for Rapa Nui (table S1). This age approximates the earliest radiocarbon values from our recent excavations at Anakena, but use of this younger age allows us to consider a large pool of radiocarbon results. By using the general approach of Spriggs and Anderson (*4*), we rejected dates on only three criteria: (i) those measured on unacceptable materials such as marine materials or terrestrial animal bone, which can be grossly affected by incorporation of old carbon from the marine reservoir effect and can have variable or poorly known correction procedures (*3*, *4*, *18*); (ii) samples of mixed isotopic fractionation (e.g., mixed charcoal and soil); and (iii) single radiocarbon dates not replicated with overlap at two standard deviations from the same archaeological context, albeit here broadly defined by stratum or adjacent strata. We used fewer criteria than Spriggs and Anderson (*4*), making our sample of dates more inclusive but more vulnerable to the acceptance of dates that are erroneously old. Applying these criteria, we have a sample of 11 radiocarbon dates of 750 yr B.P. or older: eight from excavations at Anakena, including our own, and three dates from "agricultural

idly, had immediate, major, and visible impacts on the island's biota and physical landscape, and began investing in monumental architecture and statuary within the first century or two of settlement. Although still poorly dated, monumental architecture and statuary are known from islands, such as the Societies, Marquesas, and Austral Islands, from perhaps as early as 1200 A.D. Nearly immediate building of monuments, carving giant statues, and transporting them to every corner of the island may have been cultural investments, homologous to forms elsewhere in eastern Polynesia, that mediated against overpopulation and resource shortfalls in an unpredictable environment. Such a model would help to explain the success of ancient Polynesians on tiny, remote Rapa Nui (*27*). Demographic and cultural collapse resulted from European contact beginning in 1722 A.D. with the devastating consequences of newly introduced Old World diseases to a nonimmune Polynesian population (*28*, *29*).

References and Notes

1. P. V. Kirch, J. Ellison, *Antiquity* **68**, 310 (1994).
2. A. Anderson, *Antiquity* **68**, 845 (1994).
3. A. Anderson, *J. Polynesian Soc.* **104**, 110 (1995).
4. M. Spriggs, A. Anderson, *Antiquity* **67**, 200 (1993).
5. A. Anderson, Y. Sinoto, *Asian Perspect.* **41**, 242 (2002).
6. A. Anderson, *Antiquity* **65**, 767 (1991).
7. J. Wilmshurst, T. Higham, *Holocene* **14**, 801 (2004).
8. C. Smith, in *The Archaeology of Easter Island, Vol. 1*, T. Heyerdahl, E. Ferdon, Eds. (Monographs of the School of American Research and the Museum of New Mexico, Santa Fe, NM, 1961), pp. 393–396.
9. R. Green, *J. Polynesian Soc.* **75**, 6 (1966).
10. W. Ayres, *J. Polynesian Soc.* **80**, 497 (1971).
11. J. Flenley, in *Easter Island Studies: Contributions to the History of Rapanui in Memory of William T. Mulloy*, S. R. Fischer, Ed. (Oxford Books, Oxford, 1993), pp. 27–45.
12. P. Kirch, *On the Road of the Winds: An Archaeological History of the Pacific Islands Before European Contact* (Univ. California Press, Berkeley, CA, 2000).
13. K. Butler, C. Prior, J. Flenley, *Radiocarbon* **46**, 395 (2004).
14. McGlone and Wilmshurst (*30*) document a similar problem in radiocarbon dating the inception of continuous deforestation in New Zealand. Lake and swamp cores susceptible to in-washing of old carbons yielded dates hundreds of years older than deforestation events recorded in ombrogenous peat bog strata.
15. H. Martinsson-Wallin, S. Crockford, *Asian Perspect.* **40**, 244 (2002).
16. D. Steadman, P. Vargas Casanova, C. Cristino Ferrando, *Asian Perspect.* **33**, 79 (1994).
17. T. F. G. Higham, A. G. Hogg, *Radiocarbon* **39**, 149 (1997).
18. Beck *et al.* (*31*) established a shallow-water marine reservoir correction for Rapa Nui. In the same study they report radiocarbon dating of 27 abraded coral artifacts, many identified as statue eye fragments. As listed in table S1, 15 of these dates on coral artifacts are greater than 750 yr B.P. For our analysis, we reject these dates. As Beck *et al.* correctly point out, the coral may have been collected live, or perhaps more likely given ease of access to beach cobbles, used long after the death of the coral. Beck *et al.* also warn that living coral is comprised of significantly older interior parts. We take these caveats to mean that there is no warrant to treat the death of coral and its use in artifacts as an event known to be contemporaneous or necessarily closely related in time. Indeed, the coral death ages will be systematically older than the manufacture events, but by unknowable amounts.
19. M. Stuiver, P. J. Reimer, R. W. Reimer, CALIB 5.0 (http://calib.qub.ac.uk/calib/).
20. F. G. McCormac *et al.*, *Radiocarbon* **46**, 1087 (2004).
21. P. Kirch, E. Conte, in *Archaeological Investigations in the Mangareva Islands (Gambier Archipelago), French Polynesia*, E. Conte, P. Kirch, Eds. (Archaeological Research Facility, University of California, Berkeley, 2004), pp. 149–159.
22. J. S. Athens, H. D. Tuggle, J. V. Ward, D. J. Welch, *Archaeol. Oceania* **37**, 57 (2002).
23. D. Mann *et al.*, in *Easter Island: Scientific Exploration into the World's Environmental Problems in Microcosm*, J. Loret, J. Tanacredi, Eds. (Kluwer Academic, New York, 2003), pp. 133–153.
24. A. Mieth, H.-R. Bork, *Easter Island-Rapa Nui: Scientific Pathways to Secrets of the Past* (Man and Environment I, University of Kiel, Kiel, Germany, 2004).
25. J. Diamond, W. Keegan, *Nature* **311**, 704 (1984).
26. J. Birdsell, *Cold Spring Harbor Symp. Quant. Biol.* **22**, 47 (1957).
27. T. Hunt, C. P. Lipo, in *Pacific 2000: Proceedings of the Fifth International Conference on Easter Island and the Pacific*, C. Stevenson, G. Lee, F. Morin, Eds. (Easter Island Foundation, Los Osos, USA, 2001), pp. 103–115.
28. P. Rainbird, *World Archaeol.* **33**, 436 (2002).
29. B. Peiser, *Energy Environ.* **16**, 513 (2005).
30. M. S. McGlone, J. M. Wilmshurst, *Quaternary Int.* **59**, 5 (1999).
31. J. W. Beck, L. Hewitt, G. S. Burr, J. Loret, F. Torres Hochstetter, in *Easter Island: Scientific Exploration into the World's Environmental Problems in Microcosm*, J. Loret, J. Tanacredi, Eds. (Kluwer Academic, New York, 2003), pp. 93–111.

Reward Timing in the Primary Visual Cortex

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We discovered that when adult rats experience an association between visual stimuli and subsequent rewards, the responses of a substantial fraction of neurons in the primary visual cortex evolve from those that relate solely to the physical attributes of the stimuli to those that accurately predict the timing of reward. In addition to revealing a remarkable type of response plasticity in adult V1, these data demonstrate that reward-timing activity—a "higher" brain function—can occur very early in sensory-processing paths. These findings challenge the traditional interpretation of activity in the primary visual cortex.

Primary visual cortex (V1) is the most peripheral station in the ascending visual pathway where information from the two eyes is combined, and specific features of visual stimuli, such as orientation and direction of movement, are represented by neural activity (*1*, *2*). It has long been held that, although the quality of sensory experience is used to fine-tune visual response properties during a critical period of early postnatal life, plasticity of visual responses in adults is sharply limited so as to ensure that sensory processing is reliable and reproducible. Only after the initial processing in V1 are subsequent brain regions thought to be engaged to elaborate on the significance of visual input, holding it in working memory (*3*–*8*), attributing behavioral and predictive value (*9*–*12*), and ultimately engendering appropriate behaviors.

The view of adult primary visual cortex as an immutable feature detector has undergone revision in recent years. It is now understood that deprivation and selective visual experience continue to alter cortical responsiveness in adulthood (*13*, *14*) and that V1 activity can be rapidly modulated in various behavioral contexts (*15*–*18*). However, all these changes in activity can still be readily interpreted in the context of visual processing. Our experiments challenge current understanding of what activity in V1 represents.

Adult, Long-Evans rats were fitted with head-mounted goggles that delivered full-field retinal illumination for 0.4 s to either the right eye or the left eye (fig. S1a). Action potentials evoked in response to these stimuli were monitored with chronically implanted arrays of microelectrodes, subsequently confirmed by histology to have resided in the deep layers of primary visual cortex (fig. S2). Either left- or right-eye illumination was delivered when the rat neared a water tube. Left eye stimulation portended delivery of a drop of water after x licks on the water tube (fig. S1b), whereas right eye stimulation portended delivery of water after twice that number of licks, $2x$, (where x equaled 6 licks for three rats and 10 licks for two additional rats). Half of all the trials were unrewarded, so as to address whether changes in neural response were a result of reward delivery itself, or alternatively, reflected the formation of neural associations between stimuli and reward expectancy.

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