tert-Butyl Substituent as a Regiodirecting and Novel C−H Protecting Group in Cyclobutenedione-Based Benzannulation Chemistry

Fuqiang Liu and Lanny S. Liebeskind*

Sanford S. Atwood Chemistry Center, Emory University, 1515 Pierce Drive, Atlanta, Georgia 30322

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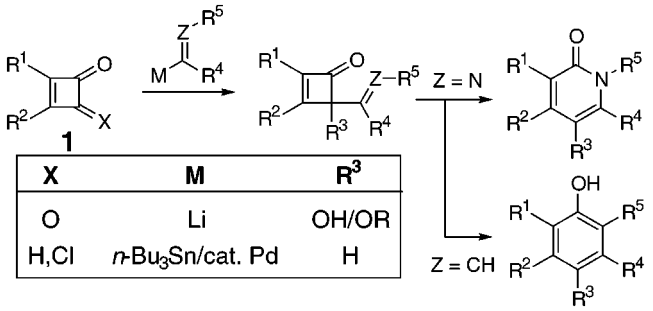
2-Unsubstituted hydroquinone monoacetates, quinones, and 3-unsubstituted quinolizinones were synthesized in moderate to high yields via *tert*-butyl and trimethylsilyl substituted cyclobutenediones. The addition of unsaturated carbon nucleophiles proceeded regiospecifically at the carbonyl group most distant from the *tert*-butyl or trimethylsilyl substituent. Thermolysis of the adducts, followed by treatment under acidic conditions to remove the *tert*-butyl and trimethylsilyl groups in good overall yields, provided access to a variety of "less-substituted" hydroquinone monoacetates, quinones, and quinolizinones. Of the two systems, the *tert*-butyl-substituted cyclobutenediones proved the most useful.

Introduction

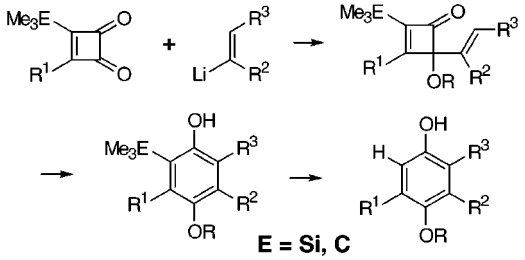
Cyclobutenediones (**1**, X = O) have been widely used in the synthesis of highly substituted aromatic molecules including phenols, catechols, hydroquinones (and quinones), and heteroaromatics (Scheme 1).[1−10] One limitation of this methodology is that, with the exception of alkoxy and amino derivatives, monosubstituted cyclobutenediones (**1**, R^1 or R^2 = H) are poor reaction partners. Most monosubstituted cyclobutenediones are less stable than their disubstituted counterparts, and the regiocontrol of the benzannulation process is compromised by competing 1,2- and 1,4-nucleophilic addition to the cyclobutenedione.

To overcome this limitation, cyclobutenediones bearing trimethylsilyl and *tert*-butyl substituents as proton surrogates were studied (Scheme 2). It was anticipated that the bulky trimethylsilyl and *tert*-butyl substituents would favorably influence the regioselectivity of nucleophilic addition. Then, after thermal rearrangement to the corresponding hydroquinone, the trimethylsilyl or *tert*-butyl groups adjacent to the phenol substituent could be cleaved by facile protodesilylation or retro-Friedel−Crafts alkylation, respectively. This would provide a regiocontrolled entry to a series of aromatic molecules at lower levels of substitution. In practice, the *tert*-butyl-substituted cyclobutenediones proved the better of the two substrates for the intended chemistry. The study documented herein revealed the *tert*-butyl substituent as an effective regiodirecting and novel C−H protecting group in the regiospecific synthesis of hydroquinone monoacetates, quinones, and quinolizinones.

Scheme 1



Scheme 2



Results

Trimethylsilyl-Substituted Cyclobutenediones. The study commenced with an exploration of the reaction of 3-methyl-4-trimethylsilylcyclobutene-1,2-dione (**2a**)[11] with 5-lithio-2,3-dihydrofuran, the latter of which was generated from *n*-butyllithium and 5-tri-*n*-butylstannyl-2,3-dihydrofuran (eq 1).[12,13] Slow dropwise addition of the lithiate to 3-methyl-4-trimethylsilylcyclobutene-1,2-dione at −78 °C followed by an Ac_2O quench and rapid workup gave an unstable product that was not amenable

* Tel no.: (404) 727-6604. FAX no.: (404) 727−0845. E-mail: CHEMLL1@unix.cc.emory.edu.

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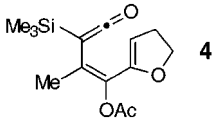

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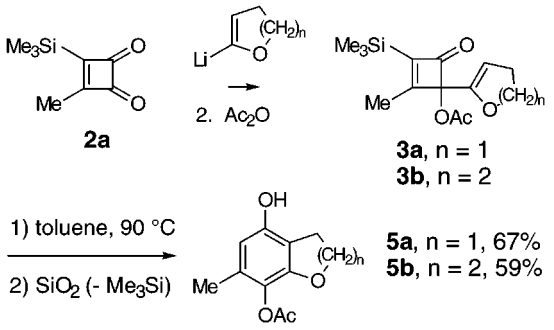
Figure 1.

to purification by chromatography. In addition to cyclobutenone absorptions at 1761 and 1744 cm^{-1}, the

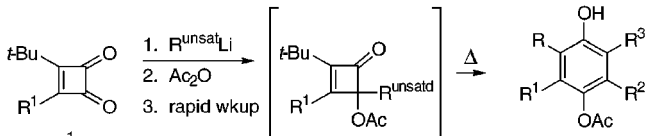


(1)

unstable product showed a strong absorption in the infrared spectrum at 2090 cm^{-1}, which suggested the presence of dienylketene **4**, generated by a facile ring opening of the cyclobutenone **3a** at room temperature (Figure 1). The ease with which cyclobutenone **3a** opened to the dienylketene is in accord with earlier studies by Tidwell, who showed that trimethylsilyl-substituted cyclobutenediones open to the isomeric bisketenes under mild conditions.[14,11] However, the untimely ring opening of the cyclobutenone compromised the efficiency of the benzannulation process by exposing the reactive dienylketene to Ac_2O/AcO^- (from the reaction quench) and to H_2O/SiO_2 (from the workup/purification). This problem was overcome when the crude reaction mixture (generated by nucleophilic addition) was rapidly washed with ice/water and then dried and heated in toluene at 90 °C for 90 min. This protocol provided the desilylated dihydrobenzofuran **5a** in 67% yield after silica gel chromatography, the desilylation occurring during chromatography. In a similar fashion, 6-lithio-*1H*-2,3-dihydropyran reacted with 3-methyl-4-trimethylsilylcyclobutene-1, 2-dione to give benzodihydropyran **5b** in 59% yield.

***tert*-Butyl-Substituted Cyclobutenediones.** To extend the process of benzannulation using trimethylsilyl-substituted cyclobutenediones, a general synthesis of 3-substituted-4-trimethylsilylcyclobutene-1,2-diones is required. Some substrates can be prepared by [2 + 2] cycloaddition of dichloroketene to 1-trimethylsilylalkynes, followed by strong acid hydrolysis of the resulting dichlorocyclobutenones to cyclobutenediones.[14] Unfortunately, this process is not general. However, a variety of 3-*tert*-butyl-4-substituted cyclobutenediones can be prepared by the sequential functionalization of diisopropylsquarate with organolithium reagents.[15] Therefore, *tert*-butyl-substituted cyclobutenediones were studied in place of the trimethylsilyl derivatives. It was anticipated that a bulky *tert*-butyl substituent might favorably influence the regioselectivity of nucleophilic addition to the cyclobutenedione, as did the trimethylsilyl substituent. After thermal rearrangement of the cyclobutenone to the substituted phenol, the *tert*-butyl group ortho to the phenol residue would be easily removed through an acid-catalyzed retro-Friedel–Crafts alkylation reaction.[16]

Table 1. Synthesis of 2-Unsubstituted Hydroquinone Monoacetates



6a, R^1 = Me
6b, R^1 = *i*-PrO

entry	R^1	$R^{unsat}Li$	**7**	R^2	R^3	**8**/%[a]	**9**/%[b]
1	Me	5-lithio-2,3-dihydrofuran	**7a**	$-OCH_2CH_2-$		**8a**/62	**9a**/92
2	*i*-PrO	5-lithio-2,3-dihydrofuran	**7b**	$-OCH_2CH_2-$		**8b**/71	**9b**/96
3	Me	6-lithio-2,3-dihydropyran	**7c**	$-O(CH_2)_3-$		**8c**/61	**9c**/93
4	*i*-PrO	6-lithio-2,3-dihydropyran	**7d**	$-O(CH_2)_3-$		**8d**/55	**9d**/96
5	Me	*β*-lithiostyrene	**7e**	H	Ph	**8e**/50	**9e**/74
6	*i*-PrO	*β*-lithiostyrene	**7f**	H	Ph	**8f**/73	**9f**/72
7	*i*-PrO	1-lithio-1-ethoxyvinyl	**7g**	OEt	H	**8g**/58	**9g**/94
8	Me	1-lithio-1-ethoxyvinyl	**7h**	OEt	H	**8h**/48	**9h**/95

[a] The yields were based on cyclobutenediones, **6**, as limiting reagents. [b] Conditions: entries 1–4 and 8, HOAc/$Zn(OAc)_2$, refluxed for 1–5 h; entry 5, TFA, 130 °C, 20 h; entry 6, TFA, 110 °C, 68 h; entry 7, Zn/HOAc, reflux 45 min.

The synthesis of 7-acetoxy-4-hydroxy-6-methyl-2,3-dihydrobenzo[*b*]furan (**9a**) is representative of the use of a *tert*-butyl substituent as a regiodirecting, C–H protecting group (Entry 1, Table 1). 5-Lithio-2,3-dihydrofuran was slowly added to 3-*tert*-butyl-4-methylcyclobutene-1,2-dione at −78 °C. Quenching with Ac_2O at −78 °C yielded **7a** (55%), which was unstable to purification and full characterization. Simply on standing at room temperature, compound **7a** transformed into **8a** within 8 h. To simplify the overall process, purification of the intermediate 1,2-adduct was foresaken. Instead, the reaction mixture was subjected to rapid workup and the crude product was heated at 120 °C for 40 min, producing **8a** in 62% yield. The *tert*-butyl substituent of **8a** was easily removed (3 equiv of $Zn(OAc)_2$ in refluxing HOAc, 90 min) giving hydroquinone monoacetate **9a** in 92% yield (Table 1, entry 1).

This representative reaction revealed three significant attributes of *tert*-butyl-substituted cyclobutenediones: (1) as with the trimethylsilyl substituent, the *tert*-butyl group functioned to control the regiochemistry of nucleophilic addition to cyclobutenediones; (2) the *tert*-butyl group significantly lowered the barrier to ring opening of the 4-acetoxy-4-substituted cyclobutenones, suggesting that relief of steric strain is a major factor in the facility of ring-opening of both systems;[14,11] and (3) the ready removal of the *tert*-butyl substituent from the thermolysis product **8a** demonstrated the potential of the *tert*-butyl substituent as a novel C–H protecting group in vinylketene-based benzannulation chemistry.

To minimize untimely ring opening of the *tert*-butyl-substituted cyclobutenones and secure optimum yields of adducts **7**, the lithium reagent must be added to the

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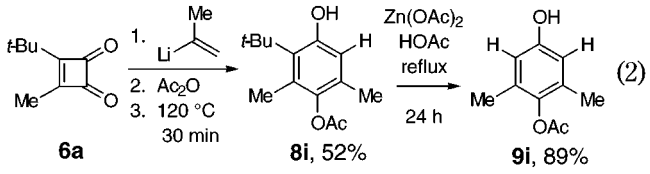
cyclobutenedione **6** slowly at −78 °C. Likewise, a rapid and cold workup of the reaction mixture was crucial, otherwise the hydrolytically sensitive dienylketene intermediate (see Figure 1) would form and be quenched by water during the workup. Using this method, a variety of *tert*-butyl-substituted hydroquinone monoacetates were synthesized in yields ranging from 48 to 73% (Table 1). In most cases, removal of the *tert*-butyl group from **8** was achieved in near quantitative yield using 3 equiv of $Zn(OAc)_2$ in refluxing HOAc for 1−5 h (entries 1−4, 7, 8). Compounds **8e** and **8f** proved resistant to deprotection under these conditions, but removal of the *tert*-butyl group was achieved by direct treatment of these substrates with a few drops of trifluoroacetic acid (20 h at 130 °C for the former; 3 d at 110 °C for the latter). This protocol produced compounds **9e** and **9f** in 70−80% yields (entries 5 and 6). For the purpose of full characterization (in addition to **7a** above), cyclobutenone intermediates **7c** and **7f** (entries 3 and 6) were isolated and purified (49% and 22% yields, respectively). When these same reactions were performed without purification of the intermediates **7**, the desired products **8c** and **8f** were obtained in 61% and 73% yields, respectively.

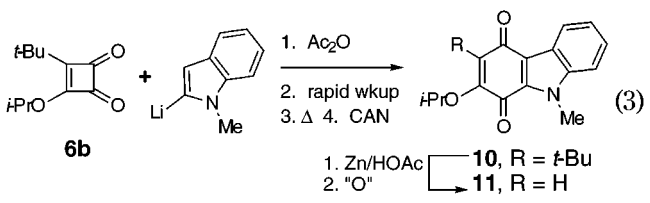
Proof of Regiochemistry. Confirmation that the *tert*-butyl group dominantly influenced the selectivity of nucleophilic addition to *tert*-butylcyclobutenediones was obtained by the addition of 2-propenyllithium to 2-*tert*-butyl-3-methylcyclobutenedione (eq 2). O-Acetylation of



(2)

the 1,2-adduct then thermolysis followed by removal of the *tert*-butyl group produced hydroquinone monoacetate **9i** in 46% overall yield. This product showed ^1H and ^{13}C NMR spectra that were fully consistent with the symmetry of the assigned structure and confirmed selective nucleophilic attack at the carbonyl group most distant from the *tert*-butyl group (eq 1). No evidence of the formation of isomeric products was obtained.

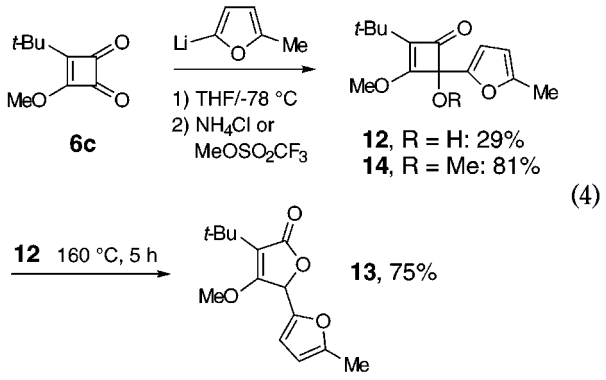
Reaction of 2-lithio-1-methylindole with 3-*tert*-butyl-4-isopropoxycyclobutene-1,2-dione followed by an Ac_2O quench and rapid workup gave a crude product that was heated at 120 °C for 30 min. The air-sensitive thermolysis product was partially oxidized to the carbazoquinone **10** (eq 3). Intentional oxidation of the crude thermolysis



(3)

product with ceric ammonium nitrate gave the red carbazoquinone **10** in 58% yield. Efficient removal of the *tert*-butyl group was achieved by subjecting **10** to reduction with Zn in refluxing HOAc (40 min). Rapid reestablishment of the quinone oxidation state occurred upon SiO_2 gel chromatography and produced the red 2-isopropoxy-9-methyl-9*H*-carbazole-1,4-dione, **11**, in 82% yield.

Surprisingly, with the exception of 2-lithio-1-methylindole (described above), aromatic and heteroaromatic reactants (PhLi, 5-lithio-2-methylfuran, and 2-lithio-1-methylpyrrole) were ineffective participants in *tert*-butyl-substituted cyclobutenedione-based benzannulation reactions. For example, addition of 5-lithio-2-methylfuran to 3-*tert*-butyl-4-methoxycyclobutene-1,2-dione (**6c**) at −78 °C gave **12** after quenching with 10% NH_4Cl (eq 4).



(4)

Upon thermolysis at 160 °C, lactone **13** was produced in 75% yield by attack of the hydroxyl group on the transiently generated vinylketene intermediate.

In an attempt to block lactone formation and promote benzannulation at the furan C=C bond, the methyl ether **14** was generated in 81% yield by addition of 5-lithio-2-methylfuran to cyclobutenedione **6c** followed by a $MeOSO_2CF_3$ quench (eq 4). This compound proved *very* resistant to thermal rearrangement and survived intact without any decomposition after 3 h at 250 °C. Slow decomposition of **14** began at 280 °C. A related attempt at benzannulation by reaction of phenyllithium and 2-lithio-1-methylpyrrole with cyclobutenedione **6b** was similarly unproductive. However, by carrying out the cyclobutenone thermolyses in xylene in the presence of Ac_2O/*n*-Bu_3N,[17] the recalcitrant reactants participated in the desired benzannulation. Under these conditions efficient formation of the benzannulated products was observed. For example, **16** was obtained in 89% yield when compound **15** was refluxed in xylene for 5 d in the presence of 3.0 equiv each of Ac_2O and *n*-Bu_3N and a catalytic amount of DMAP (Scheme 3). Depending upon the temperature, thermolysis in the absence of the additives gave either recycled starting material or resulted in decomposition. Quantitative deprotection of the acetate group ($LiAlH_4$, 5 min, rt) gave **18** which was subjected to *tert*-butyl cleavage [HOAc/$Zn(OAc)_2$, reflux] to give hydroquinone monomethyl ether **20** in 93% yield. Using the modified thermolysis conditions, acamelin (**22**), a natural product isolated from Australian blackwood (*Acacia melanoxylon*) and previously synthesized in very low yield,[18,19] was obtained in 36% overall yield in six steps from 3-*tert*-butyl-4-methoxycyclobutene-1,2-dione (Scheme 3, **6c** → **22**).

To further explore the generality of this methodology, reactions between *tert*-butyl-substituted cyclobutenediones and 2-lithio azaheteroaromatics were studied. Moderate to high yields of *tert*-butyl-substituted ring-fused

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Scheme 3

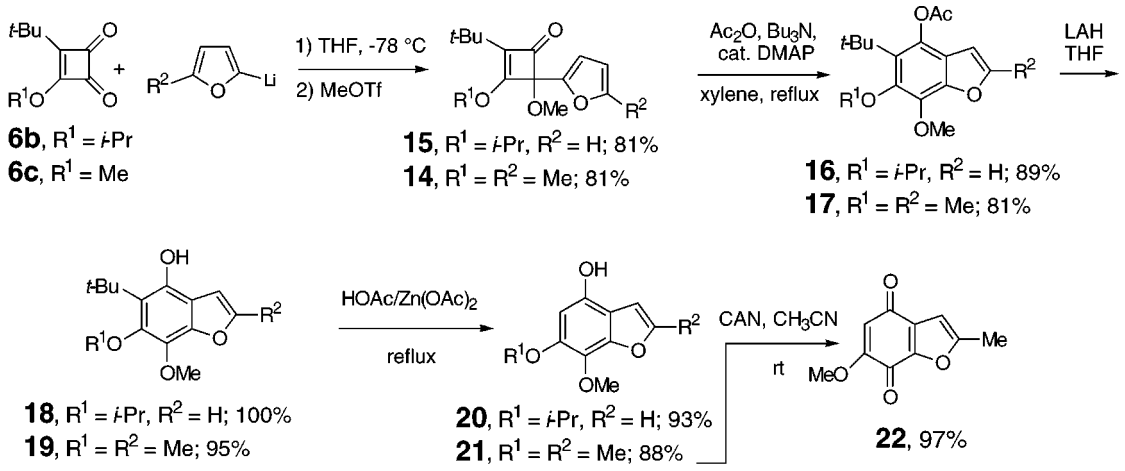
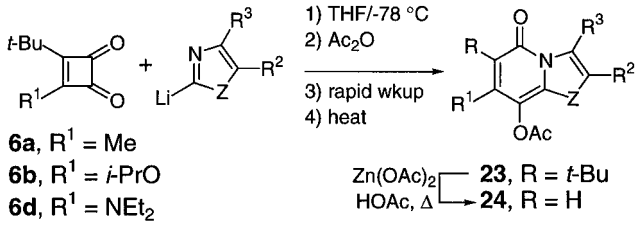


Table 2. Synthesis of Ring-fused Pyridones



entry	R^1	lithiate	Z	R^2	R^3	**23**/%	**24**/%
1	*i*-PrO	2-lithiothiazole	S	H	H	**23a**/63	**24a**/94
2	Me	2-lithiothiazole	S	H	H	**23b**/43	**24b**/92
3[a]	Et_2N	2-lithiothiazole	S	H	H	**23c**/97[a]	**24c**/100
4	*i*-PrO	2-lithiobenzothiazole	S	benzo		**23d**/59	**24d**/85
5	Me	2-lithiobenzothiazole	S	benzo		**23e**/46	**24e**/95
6	*i*-PrO	2-lithio-1-methylimidazole	NMe	H	H	**23f**/52	**24f**/99
7	Me	2-lithio-1-methylimidazole	NMe	H	H	**23g**/66	**24g**/93

[a] The lithium reagent was added to the cyclobutenedione at −78 °C, then the reaction mixture was warmed to 0 °C. After 40 min, the reaction was quenched with Ac_2O at 0 °C. A rapid workup and thermolysis at 140 °C for 30 min produced the product.

pyridones **23** were obtained by the regiospecific addition of lithiated azaheteroaromatics to *tert*-butylcyclobutene-1,2-diones **6a**, **6b**, and **6d** followed by an Ac_2O quench and thermolysis of the crude reaction products. Cleavage of the *tert*-butyl substituent proceeded with high efficiency and gave products **24** (Table 2). Compared to other *tert*-butyl-substituted cyclobutenediones, 3-diethylamino-4-*tert*-butylcyclobutenedione, **6d**, was less reactive toward nucleophilic addition. To effect the addition, the reaction mixture was warmed to 0 °C for 40 min. Quenching with Ac_2O at 0 °C followed by neat thermolysis of the crude product at 140 °C for 30 min gave compound **23c** in 97% yield. The transformation from **23c** to **24c** (quantitative) in refluxing HOAc with added $Zn(OAc)_2$ was complete within 10 min.

Discussion

Why do not 2-*tert*-butyl-4-aryl (and most 4-heteroaryl) cyclobutenones undergo thermal rearrangement to the benzannulated products under reaction conditions where 2-*tert*-butyl-4-alkenyl (and heteroalkenyl) cyclobutenones do? And why, when the 2-*tert*-butyl substituent is replaced with a less bulky substituent, do thermal benzannulations proceed regardless of the nature of the unsaturated moiety at the 4-position of the cyclobutenone?[1,3] For example, it was previously observed that 2,3-dimethoxy-4-hydroxy-4-(2-furyl)cyclobutenone and 2-methyl-3-methoxy-4-hydroxy-4-(2-furyl)cyclobutenone rearrange to the corresponding furan-fused quinones with facility.[1,3] But in the current study, 2-*tert*-butyl-3,4-dimethoxy-4-(5-methyl-2-furyl)cyclobutenone is stable at 250 °C for 3 h, while 2-*tert*-butyl-3-isopropoxy-4-acetoxy-4-(2,3-dihydrofuran-5-yl) undergoes thermal rearrangment within 30 min at 120 °C.

The cumulative results obtained to date indicate that an interplay between the steric nature of the cyclobutenone 2-substituent and the nucleophilic nature of the 4-$R^{unsaturated}$ substituent affects the facility with which 4-$R^{unsaturated}$ cyclobutenones are converted into benzannulated products. Since sterically encumbered cyclobutenones appear to open to the vinylketene at room temperature (see above), it is unlikely that generation of the vinylketene intermediate is the rate-determining step in the benzannulation of these substrates; electrocyclization must be the slow step in the overall process. It therefore follows that, as the central carbon of the ketene and the π-orbital at the alkene β-carbon approach each other for bonding (Figure 2), the reaction rate is retarded by any nonbonded steric effects that emerge between the vinylketene 2- and 3-substituents.

With 2-*tert*-butyl-substituted cyclobutenones, nonbonded steric interactions between the *tert*-butyl group and

Figure 2. Representations of vinylketene electrocyclization leading to benzannulation products.

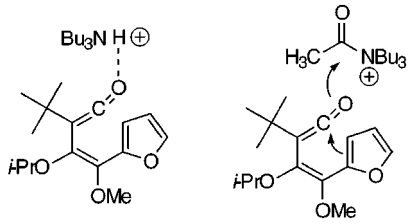


Figure 3.

the adjacent ketene substituent become pronounced as the alkene substituent and the ketene central carbon approach each other. However, those cyclobutenones bearing nucleophilic 4-substituents (dihydrofuran, dihydropyran, and indole) can attain a bonding interaction with the ketene central carbon at distances where the less nucleophilic π-systems fail to react. Therefore, steric retardation of the electrocyclization by the *tert*-butyl group is diminished or nullified with cyclobutenones bearing 4-substituents with nucleophilic π-systems. Alternatively, replacement of the bulky 2-*tert*-butyl substituent with a smaller group diminishes nonbonded steric effects and allows closer approach of the less nucleophilic π-systems (phenyl, substituted phenyl, furan, and *N*-methylpyrrole) to the ketene central carbon. This contributes to faster rates of electrocyclization and to a faster overall rate of reaction, thus allowing effective benzannulation with aromatic, heteroaromatic, or vinyl substituents at the 4-position of the cyclobutenone.[1,3]

What is the beneficial effect of Ac_2O/*n*-Bu_3N on the problematic electrocyclizations? Consistent with the mechanistic arguments elaborated above, the barrier to electrocyclization should be lowered by electrophilic polarization of the ketene carbonyl group. At the elevated temperatures required to achieve an acceptable reaction rate, ketene polarization might occur either with catalytic quantities of *n*-$Bu_3NH^+AcO^-$ (generated by *n*-Bu_3N deprotonation of Ac_2O) or by interaction of the ketene with $CH_3CONBu_3^+AcO^-$ (Figure 3). Alternatively, O-acylation of the cyclobutenone carbonyl would produce a cyclobutenyl cation; ring-expansion could then occur by analogy with the acid-induced ring expansion of 2-vinylcyclobutanones to cyclohexenones (Figure 4).[20]

Compared to 2-*tert*-butyl-4-arylcyclobutenones, the facility with which 2-*tert*-butylcyclobutenones bearing π-deficient 4-azaheteroaryl substituents cyclize to ring-fused pyridones is readily explained by participation of the in-plane, nonbonding electron pair on nitrogen in the electrocyclization process (Figure 5). The ease with which the *tert*-butyl group is lost from ring-fused pyridones **23** also requires explanation. Removal of the *tert*-butyl substituent from hydroquinone monoacetates **8** proceeds through protonation of the *tert*-butyl bearing carbon atom, either by an acid catalyst or by tautomer-

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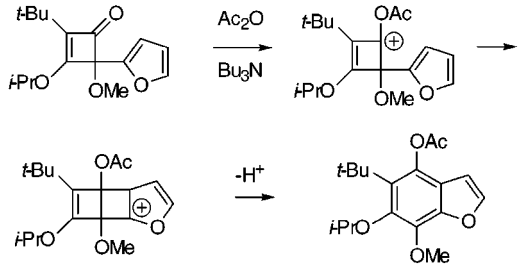


Figure 4.

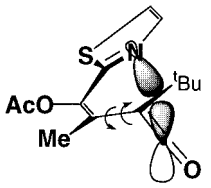
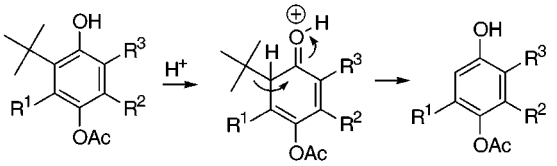


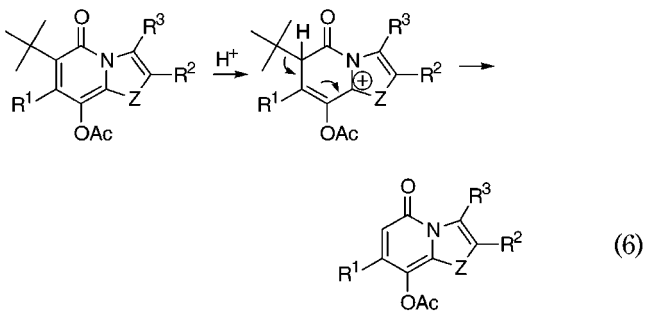
Figure 5. Representation of vinylketene electrocyclization leading to **23b**.

ization of the phenol (eq 5). Since tautomerization of the



(5)

ring-fused pyridones is not feasible, it is presumed that the pyridones suffer facile protonation at the *tert*-butyl bearing carbon atom, which must be a consequence of considerable stabilization of the charge by delocalization into the adjacent heterocyclic ring (eq 6).



(6)

Conclusions

tert-Butyl-substituted cyclobutenediones undergo regiospecific addition of unsaturated carbon nucleophiles at the carbonyl group most distant from the *tert*-butyl substituent. Good to high yields of 2-*tert*-butyl-substituted hydroquinone monoacetates, quinones, and 3-*tert*-butyl-substituted quinolizinones were synthesized by thermolysis of the O-acetylated and O-methylated adducts. Very efficient removal of the *tert*-butyl group is accomplished under acidic conditions for the 2-*tert*-butyl-substituted hydroquinone monoacetates and 3-*tert*-butyl-substituted quinolizinones and under acidic reducing conditions for the 2-*tert*-butylquinones, thus providing a synthetic entry to 2-unsubstituted hydroquinone monoacetates and quinones and to 3-unsubstituted quinolizinones.

Experimental Section

General Experimental. All reactions were performed under an atmosphere of dry prepurified nitrogen in flame-dried glassware. Et_2O was freshly distilled from sodium and benzophenone under nitrogen. Prior to use, THF, toluene, and xylene were dried with 4 Å molecular sieves and analyzed for less than 30 ppm H_2O by Karl Fischer titration. *n*-BuLi and *tert*-BuLi solutions were purchased from Aldrich in Sure-Seal bottles and were titrated using diphenylacetic acid as indicator. $Zn(OAc)_2$ and (1-ethoxyvinyl)tri-*n*-butyltin were purchased from Aldrich and used as received. Thin-layer chromatography was performed with E. Merck silica gel 60F-245 glass plates of 0.25 mm thickness using UV light and anisaldehyde stain solution for visualization. Column chromatography was carried out using flash grade silica gel 60 (EM Science) with compressed air as the source of positive pressure.

Starting Materials. The following compounds were prepared by literature methods: 3-methyl-4-trimethylsilylcyclobut-3-ene-1, 2-dione (**2a**),[11] 3-*tert*-butyl-4-isopropoxycyclobutene-1,2-dione (**6b**),[15] 3-*tert*-butyl-4-methylcyclobutene-1,2-dione (**6a**),[15] 5-tri-*n*-butylstannyl-2,3-dihydrofuran,[13] 6-tri-*n*-butylstannyl-2,3-dihydropyran,[13] *β*-tri-*n*-butylstannylstyrene,[21] 2-tri-*n*-butylstannylthiazole,[22] 2-tri-*n*-butylstannyl-1-methylimidazole,[22] 2-tri-*n*-butylstannylbenzothiazole,[8] and 3,4-dimethoxycyclobutene-1,2-dione.[23]

***N*-Methyl-2-tri-*n*-butylstannylindole.** Under argon, 1-methylindole (5.31 g, 40.48 mmol, 1.00 equiv) was dissolved in 70 mL of THF and cooled to −78 °C. *tert*-Butyllithium (28.57 mL, 1.70 M in pentane, 48.57 mmol, 1.20 equiv) was added dropwise. The reaction mixture was warmed to room temperature, stirred for 2 h, and then recooled to −78 °C. Tri-*n*-butylstannyl chloride (13.18 mL, 48.59 mmol, 1.20 equiv) was added dropwise, and the mixture was stirred for 2 h and then quenched with 10% aqueous NH_4Cl and extracted with 3 × 70 mL of Et_2O. The combined organic layers were dried with $MgSO_4$ and concentrated to an oil. Purification by distillation gave *N*-methyl-2-tri-*n*-butylstannylindole, a yellow oil (14.16 g, 33.70 mmol, 83%). Bp: 163−165 °C (0.1 mmHg, short-path distillation). IR (CH_2Cl_2, KCl, cm^{-1}): 3060, 2958, 2933, 1416, 1356. ^1H NMR ($CDCl_3$, 300 MHz): δ 7.58 (d, J = 7.8 Hz, 1 H), 7.31 (d, J = 7.8 Hz, 1 H), 7.17 (dt, J = 7.8, 6.9 Hz, 1 H), 7.06 (dt, J = 7.8, 6.9 Hz, 1 H), 6.59 (s, 1 H), 3.80 (s, 3 H), 1.62−1.52 (m, 6 H), 1.41−1.29 (m, 6 H), 1.18−1.12 (m, 6 H), 0.89 (t, J = 7.2 Hz, 9 H). HRMS (EI) Calcd for $C_{21}H_{35}NSn$: 421.1791. Found: 421.1791.

3-*tert*-Butyl-4-methoxycyclobutene-1,2-dione, 6c. 3,4-Dimethoxycyclobutene-1,2-dione (284 mg, 1.998 mmol, 1.00 equiv) in 6 mL of THF under N_2 at −78 °C was treated dropwise with *tert*-BuLi in pentane (1.29 mL, 1.70 M, 2.190 mmol, 1.10 equiv). After 10 min the reaction was quenched with saturated $NaHCO_3$ (1 mL), washed with H_2O, extracted with Et_2O (30 mL × 2), dried ($MgSO_4$), filtered, and concentrated. The resulting colorless oil in 5 mL of CH_2Cl_2 was treated at room temperature with 3 drops of concentrated HCl. After 15 min, the mixture was diluted with 20 mL of CH_2Cl_2 and dried over K_2CO_3. After filtration and evaporation, the yellow oil was purified by chromatography (flash column, silica gel, 2 × 8 cm, 15% ethyl acetate in hexane) to yield **6c** as a yellow oil (227 mg, 1.350 mmol, 68%). TLC: silica gel, 15% ethyl acetate in hexane, R_f = 0.25). IR (CH_2Cl_2, NaCl, cm^{-1}): 2974 (s), 1792 (s), 1761 (s), 1589 (s), 1482 (s). ^1H NMR ($CDCl_3$, 300 MHz): δ 4.36 (s, 3 H), 1.25 (s, 9 H). ^{13}C NMR ($CDCl_3$, 75.5 MHz): δ 196.9, 194.6, 194.2, 190.8, 60.9, 34.2, 26.9 (3 C). Anal. Calcd for $C_9H_{12}O_3$: C, 64.27; H, 7.19; O, 28.54. Found: C, 64.35; H, 7.24.

3-*tert*-Butyl-4-diethylaminocyclobutene-1,2-dione, 6d. 3-*tert*-Butyl-4-isopropoxycyclobutene-1,2-dione (3.92 g, 19.970 mmol, 1.00 equiv) in 25 mL of THF was treated with diethylamine (16.55 mL, 159.980 mmol, 8.01 equiv). After 4 d at room temperature the solvent was evaporated, yielding a yellow oil which was purified by vacuum distillation (bp 130−132 °C/0.01 mmHg) followed by recrystallization from Et_2O/hexane (mp 54−55 °C) to give **6d** as a light yellow solid (3.27 g, 15.620 mmol, 78%). TLC: silica gel, 25% ethyl acetate in hexane, R_f = 0.18). IR (CH_2Cl_2, NaCl, cm^{-1}): 2982 (m), 1775 (s), 1725 (s), 1585 (s). ^1H NMR ($CDCl_3$, 300 MHz): δ 3.66 (br s, 4 H), 1.35 (s, 9 H), 1.22 (t, J = 7.2 Hz, 6 H). ^{13}C NMR ($CDCl_3$, 75.5 MHz): δ 194.4, 190.0, 180.5, 176.8, 46.0 (br s, 1 C), 44.0 (br s, 1 C), 34.0, 29.3 (3 C), 13.5 (br s, 2 C). Anal. Calcd for $C_{12}H_{19}NO_2$: C, 68.87; H, 9.15; N, 6.69; O, 15.29. Found: C, 68.77; H, 9.18; N, 6.67.

Benzannulation with Trimethylsilylcyclobutenediones. 7-Acetoxy-4-hydroxy-6-methyl-2,3-dihydrobenzo[*b*]furan, 5a. 5-Tri-*n*-butylstannyl-2,3-dihydrofuran (485 mg, 1.350 mmol, 1.35 equiv) in THF (5 mL) at −78 °C was treated dropwise with *n*-BuLi in hexane (1.11 mL, 1.25 M, 1.400 mmol, 1.40 equiv). After warming to 0 °C for 30 min, the mixture was added very slowly dropwise to 3-methyl-4-trimethylsilylcyclobut-3-ene-1,2-dione (168 mg, 0.998 mmol, 1.00 equiv) in THF (5 mL) at −78 °C. After 2 h, Ac_2O (284 mL, 3.010 mmol, 3.02 equiv) was added, and the mixture was maintained at −78 °C for 90 min and then quickly washed with H_2O, extracted with Et_2O (50 mL × 2), dried ($MgSO_4$), and concentrated to a yellow oil. This crude material was dissolved in 6 mL of toluene, heated in a flame-dried flask at 90 °C (N_2) for 90 min, and then purified by chromatography (flash column, silica gel, 2 × 15 cm, 25% ethyl acetate in hexane) to yield **5a** as a yellow oil (139 mg, 0.667 mmol, 67%). TLC: silica gel, 25% ethyl acetate in hexane, R_f = 0.13). IR (CH_2Cl_2, NaCl, cm^{-1}): 3685 (w), 3579 (s), 3467 (s), 1762 (s), 1606 (s. ^1H NMR ($CDCl_3$, 300 MHz): δ 6.08 (s, 1 H), 5.30 (s, 1 H), 4.64 (t, J = 8.7 Hz, 2 H), 3.12 (t, J = 8.7 Hz, 2 H), 2.31 (s, 3 H), 2.07 (s, 3 H). ^{13}C NMR ($CDCl_3$, 75.5 MHz): δ 169.9, 152.0, 150.0, 130.7, 126.7, 112.0, 109.3, 72.8, 27.2, 20.4, 15.7. Anal. Calcd for $C_{11}H_{12}O_4$: C, 63.45; H, 5.81; O, 30.74. Found: C, 63.33; H, 5.83.

8-Acetoxy-5-hydroxy-7-methyldihydrobenzo[*b*]pyran, 5b. 6-Tri-*n*-butylstannyl-2,3-dihydropyran (429 mg, 1.150 mmol, 1.15 equiv) in THF (5 mL) at −78 °C was treated dropwise with *n*-BuLi in hexane (0.55 mL, 2.19 M, 1.200 mmol, 1.20 equiv). The reaction mixture was warmed to 0 °C for 30 min and then added very slowly dropwise to 3-methyl-4-trimethylsilylcyclobut-3-ene-1,2-dione (168 mg, 0.998 mmol, 1.00 equiv) in THF (5 mL) at −78 °C. After 3 h, Ac_2O (189 mL, 2.010 mmol, 2.00 equiv) was added, and the mixture was maintained at −78 °C for 90 min and then quickly washed with H_2O, extracted with Et_2O (50 mL × 2), dried ($MgSO_4$), and concentrated to a yellow oil. This crude material was dissolved in 6 mL of toluene, refluxed in a flame-dried flask for 2 h, and then purified by chromatography (flash column, silica gel, 1 × 15 cm, 25% ethyl acetate in hexane) to yield **5b** as an orange oil (131 mg, 0.585 mmol, 59%). TLC: silica gel, 25% ethyl acetate in hexane, R_f = 0.20). IR (CH_2Cl_2, NaCl, cm^{-1}): 3586 (s), 1758 (s), 1689 (m), 1634 (m), 1591 (m). ^1H NMR ($CDCl_3$, 300 MHz): δ 6.02 (s, 1 H), 5.73 (br s, 1 H), 4.13 (t, J = 4.8 Hz, 2 H), 2.57 (t, J = 6.3 Hz, 2 H), 2.32 (s, 3 H), 2.03 (s, 3 H), 1.98 (tt, J = 6.3, 4.8 Hz, 2 H). ^{13}C NMR ($CDCl_3$, 75.5 MHz): δ 170.2, 151.4, 146.8, 131.0, 128.2, 108.7, 107.5, 66.2, 21.4, 20.5, 19.0, 15.7. Anal. Calcd for $C_{12}H_{14}O_4$: C, 64.85; H, 6.35; O, 28.80. Found: C, 64.57; H, 6.30.

Isolation of Intermediates 7a, 7c, and 7f. 4-Acetoxy-2-*tert*-butyl-4-[5′-(2′,3′-dihydrofuranyl)]-3-methyl-2-cyclobutenone, 7a. 5-Tri-*n*-butylstannyl-2,3-dihydrofuran (345 mg, 0.961 mmol, 1.20 equiv) in THF (6 mL) at −78 °C was treated dropwise with *n*-BuLi in hexane (0.80 mL, 1.25 M, 1.000 mmol, 1.25 equiv). The reaction mixture was warmed to 0 °C for 30 min and then added very slowly dropwise to 3-*tert*-butyl-4-methylcyclobutene-1,2-dione (122 mg, 0.802 mmol, 1.00 equiv) in THF (6 mL) at −78 °C. After 1 h, Ac_2O (226 μL, 2.395 mmol, 2.99 equiv) was added, and the mixture was maintained at −78 °C for 90 min and then washed with H_2O, extracted with Et_2O (50 mL × 2), dried ($MgSO_4$), filtered, and concentrated to a yellow oil. Chromatography (flash column, silica gel, 2 × 15 cm, 20% ethyl acetate in hexane) yielded **7a** as a yellow oil (115 mg, 0.435 mmol, 54%). TLC: silica gel,

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20% ethyl acetate in hexane, $R_f = 0.30$). IR (CH_2Cl_2, NaCl, cm^{-1}): 3055 (m), 2970 (s), 1769 (s), 1744 (s), 1621 (m). ^1H NMR ($CDCl_3$, 300 MHz): δ 4.93 (t, $J = 2.4$ Hz, 1 H), 4.36 (dt, $J = 9.3$, 3.0 Hz, 2 H), 2.68 (dt, $J = 9.3$, 2.4 Hz, 2 H), 2.23 (s, 3 H), 2.05 (s, 3 H), 1.20 (s, 9 H).

4-Acetoxy-2-*tert*-butyl-4-[6′-(2′,3′-dihydropyranyl)]-3-methyl-2-cyclobutenone, 7c. 6-Tri-*n*-butylstannyl-2,3-dihydropyran (358 mg, 0.959 mmol, 1.20 equiv) in THF (5 mL) at −78 °C was treated dropwise with *n*-BuLi in hexane (0.80 mL, 1.25 M, 1.000 mmol, 1.25 equiv). The reaction mixture was warmed to 0 °C in a bath for 30 min and then added very slowly dropwise to 3-*tert*-butyl-4-methylcyclobutene-1,2-dione (122 mg, 0.802 mmol, 1.00 equiv) in THF (5 mL) at −78 °C. Ac_2O (226 μL, 2.395 mmol, 2.99 equiv) quench and workup as for **7a** gave a yellow oil that was purified by chromatography (flash column, silica gel, 2 × 15 cm, 25% ethyl acetate in hexane) to yield **7c** as an orange oil (110 mg, 0.395 mmol, 49%). TLC: silica gel, 25% ethyl acetate in hexane, $R_f = 0.36$). IR (CH_2Cl_2, NaCl, cm^{-1}): 3054 (m), 2971 (s), 1767 (s), 1744 (m), 1668 (m), 1618 (w), 1588 (m). ^1H NMR ($CDCl_3$, 300 MHz): δ 4.87 (t, $J = 3.9$ Hz, 1 H), 4.02 (m, 2 H), 2.22 (s, 3 H), 2.06 (s, 3 H), 2.05 (dt, $J = 6.3$, 3.9 Hz, 2 H), 1.80 (tt, $J = 6.3$, 5.4 Hz, 2 H), 1.21 (s, 9 H). ^{13}C NMR ($CDCl_3$, 75.5 MHz): δ 185.8, 169.6, 168.9, 162.8, 147.9, 98.5, 97.0, 66.5, 32.7, 27.8 (3 C), 22.0, 21.2, 19.9, 13.6. Anal. Calcd for $C_{16}H_{22}O_4$: C, 69.04; H, 7.97; O, 22.99. Found: C, 68.90; H, 7.98.

(*E*)-4-Acetoxy-2-*tert*-butyl-3-isopropoxy-4-(*β*-styrene)-2-cyclobutenone, 7f. (*E*)-*β*-Tri-*n*-butylstannylstyrene (472 mg, 1.200 mmol, 1.20 equiv) in THF (5 mL) at −78 °C was treated dropwise with *n*-BuLi in hexane (1.00 mL, 1.25 M, 1.250 mmol, 1.25 equiv). The reaction mixture was warmed to 0 °C in a bath for 30 min and then added very slowly to 3-*tert*-butyl-4-isopropoxycyclobutene-1,2-dione (196 mg, 0.999 mmol, 1.00 equiv) in THF (5 mL) at −78 °C. Ac_2O (283 μL, 2.999 mmol, 3.00 equiv) quench and workup as for **7a** gave a yellow oil that was purified by chromatography (flash column, silica gel, 1 × 15 cm, 25% ethyl acetate in hexane) to yield **7f** as a yellow oil (76 mg, 0.222 mmol, 22%). TLC: silica gel, 25% ethyl acetate in hexane, $R_f = 0.31$). ^1H NMR ($CDCl_3$, 300 MHz): δ 7.39−7.24 (m, 5 H), 6.74 (d, $J = 16.2$ Hz, 1 H), 6.30 (d, $J = 16.2$ Hz, 1 H), 4.66 (sept, $J = 6.0$ Hz, 1 H), 2.13 (s, 3 H), 1.32 (d, $J = 6.0$ Hz, 3 H), 1.31 (d, $J = 6.0$ Hz, 3 H), 1.22 (s, 9 H).

Synthesis of *tert*-Butylphenols 8 without Isolation of Intermediates 7. Typical Procedure. 7-Acetoxy-5-*tert*-butyl-4-hydroxy-6-methyl-2,3-dihydrobenzo[*b*]furan, 8a. 5-Tri-*n*-butylstannyl-2,3-dihydrofuran (517 mg, 1.440 mmol, 1.20 equiv) in THF (7 mL) at −78 °C was treated dropwise with *n*-BuLi in hexane (1.20 mL, 1.25 M, 1.500 mmol, 1.25 equiv). The reaction mixture was warmed to 0 °C for 30 min and then added very slowly dropwise to 3-*tert*-butyl-4-methylcyclobutene-1,2-dione (183 mg, 1.202 mmol, 1.00 equiv) in THF (7 mL) at −78 °C. After 1 h, Ac_2O (340 μL, 3.603 mmol, 3.00 equiv) was added, and the mixture was maintained at −78 °C for 10 min and then quickly washed with H_2O, extracted with Et_2O (50 mL × 2), dried ($MgSO_4$), and concentrated to a yellow oil. This crude material was heated neat under N_2 in a flame-dried flask at 120 °C for 40 min and then purified by chromatography (flash column, silica gel, 2 × 15 cm, 25% ethyl acetate in hexane) to yield **8a** as a yellow oil (195 mg, 0.738 mmol, 61%). TLC: silica gel, 25% ethyl acetate in hexane, $R_f = 0.23$). IR (CH_2Cl_2, NaCl, cm^{-1}): 1760 (s), 1685 (m), 1636 (m), 1601 (m). ^1H NMR ($CDCl_3$, 300 MHz): δ 4.86 (s, 1 H), 4.61 (t, $J = 8.7$ Hz, 2 H), 3.10 (t, $J = 8.7$ Hz, 2 H), 2.31 (s, 3 H), 2.26 (s, 3 H), 1.53 (s, 9 H). ^{13}C NMR ($CDCl_3$, 75.5 MHz): δ 169.2, 149.2, 129.9, 127.6, 127.5, 126.6, 112.8, 72.3, 37.3, 32.7 (3 C), 27.6, 20.4, 15.7. Anal. Calcd for $C_{15}H_{20}O_4$: C, 68.16; H, 7.63; O, 24.21. Found: C, 68.18; H, 7.66.

The experimental details and characterization data for compounds **8b**−**i** are found in the Supporting Information.

Synthesis of 9 by Acid-Catalyzed Removal of *tert*-Butyl Substituents from 8. Typical Procedure. 7-Acetoxy-4-hydroxy-6-methyl-2,3-dihydrobenzo[*b*]furan, 9a. 7-Acetoxy-5-*tert*-butyl-4-hydroxy-6-methyl-2,3-dihydrobenzo[*b*]furan, **8a** (91 mg, 0.344 mmol, 1.00 equiv), and anhydrous $Zn(OAc)_2$ (189 mg, 1.030 mmol, 2.99 equiv) were dissolved in 1 mL of HOAc and refluxed for 90 min. The liquid phase was removed by pipet and condensed on a rotoary evaporator, leaving a crude product that was purified by chromatography (flash column, silica gel, 1 × 15 cm, 25% ethyl acetate in hexane) to give **9a** as a yellow oil (66 mg, 0.317 mmol, 92%). TLC: silica gel, 25% ethyl acetate in hexane, $R_f = 0.13$). IR (CH_2Cl_2, NaCl, cm^{-1}): 1762 (s), 1606 (s). ^1H NMR ($CDCl_3$, 300 MHz): δ 6.08 (s, 1 H), 5.30 (s, 1 H), 4.64 (t, $J = 8.7$ Hz, 2 H), 3.12 (t, $J = 8.7$ Hz, 2 H), 2.31 (s, 3 H), 2.07 (s, 3 H). ^{13}C NMR ($CDCl_3$, 75.5 MHz): δ 169.9, 152.0, 150.0, 130.7, 126.7, 112.0, 109.3, 72.8, 27.2, 20.4, 15.7. Anal. Calcd for $C_{11}H_{12}O_4$: C, 63.45; H, 5.81; O, 30.74. Found: C, 63.33; H, 5.83.

The experimental details and characterization data for compounds **9b**−**i** are found in the Supporting Information.

Synthesis of Carbazoloquinones 10 and 11 from *N*-Methylindole. 3-*tert*-Butyl-2-isopropoxy-9-methyl-9*H*-carbazole-1,4-dione, 10. 1-Methyl-2-tri-*n*-butylstannylindole (565 mg, 1.345 mmol, 1.20 equiv) in THF (6 mL) at −78 °C was treated dropwise with *n*-BuLi in hexane (1.12 mL, 1.25 M, 1.400 mmol, 1.25 equiv). The reaction mixture was warmed to 0 °C for 30 min and then added very slowly dropwise to 3-*tert*-butyl-4-isopropoxycyclobutene-1,2-dione (220 mg, 1.121 mmol, 1.00 equiv) in THF (6 mL) at −78 °C. After 30 min, Ac_2O (317 μL, 3.360 mmol, 3.00 equiv) was added and the mixture was stirred at −78 °C for 20 min. The reaction mixture was rapidly washed with H_2O, extracted with Et_2O (50 mL × 2), dried ($MgSO_4$), filtered, and concentrated to a yellow solid that was heated neat in a flame-dried flask at 120 °C for 20 min. The crude thermolysis product was oxidized with excess ceric ammonium nitrate in a mixture of Et_2O (10 mL) and H_2O (5 mL) at room temperature. The resulting red product was purified by chromatography (flash column, silica gel, 2 × 15 cm, 15% ethyl acetate in hexane) to yield **10** as a red solid (211 mg, 0.648 mmol, 58%). TLC: silica gel, 15% ethyl acetate in hexane, $R_f = 0.51$. Mp: 126−128 °C (methylene chloride/hexane). IR (CH_2Cl_2, NaCl, cm^{-1}): 1684 (s), 1662 (s), 1638 (m), 1614 (w). ^1H NMR ($CDCl_3$, 300 MHz): δ 8.29 (d, $J = 7.8$ Hz, 1 H), 7.41−7.26 (m, 3 H), 4.87 (sept, $J = 6.0$ Hz, 1 H), 4.07 (s, 3 H), 1.46 (s, 9 H), 1.35 (d, $J = 6.0$ Hz, 6 H). ^{13}C NMR ($CDCl_3$, 75.5 MHz): δ 185.4, 178.1, 154.9, 141.0, 140.0, 131.8, 126.7, 124.0, 123.7, 123.4, 118.3, 110.5, 75.6, 36.4, 32.0 (3 C), 31.5, 22.6 (2 C). Anal. Calcd for $C_{20}H_{23}NO_3$: C, 73.82; H, 7.12; N, 4.30; O, 14.75. Found: C, 73.69; H, 7.22; N, 4.05.

2-Isopropoxy-9-methyl-9*H*-carbazole-1,4-dione, 11. 3-*tert*-Butyl-2-isopropoxy-9-methyl-*9H*-carbazole-1,4-dione, **10** (160 mg, 0.492 mmol, 1.00 equiv), and Zn powder (96.4 mg, 1.475 mmol, 3.00 equiv) were refluxed in 2 mL of HOAc for 40 min. Evaporation and chromatography (flash column, silica gel, 1 × 15 cm, 25% ethyl acetate in hexane) provided **11** as a red solid (108 mg, 0.401 mmol, 82%). TLC: silica gel, 25% ethyl acetate in hexane, $R_f = 0.32$. Mp: 140−142 °C (methylene chloride/hexane). IR (CH_2Cl_2, NaCl, cm^{-1}): 1680 (s), 1635 (m). ^1H NMR ($CDCl_3$, 300 MHz): δ 8.24 (d, $J = 8.1$ Hz, 1 H), 7.42−7.23 (m, 3 H), 5.72 (s, 1 H), 4.51 (sept, $J = 6.0$ Hz, 1 H), 4.07 (s, 3 H), 1.44 (d, $J = 6.0$ Hz, 6 H). ^{13}C NMR ($CDCl_3$, 75.5 MHz): δ 183.9, 175.7, 156.8, 139.9, 132.3, 126.9, 124.2, 123.3, 123.1, 116.9, 110.6, 108.3, 72.2, 31.6, 21.2 (2 C). Anal. Calcd for $C_{16}H_{15}NO_3$: C, 71.36; H, 5.61; N, 5.20; O, 17.82. Found: C, 71.68; H, 5.63; N, 5.09.

Thermolysis of Cyclobutenones 12 and 14. Synthesis of Lactone 13. 2-*tert*-Butyl-4-hydroxy-3-methoxy-4-[5-(2-methylfuryl)]-2-cyclobutenone, 12. A mixture of 2-methylfuran (119 mg, 1.449 mmol, 1.25 equiv) and TMEDA (168 mg, 1.446 mmol, 1.25 equiv) in Et_2O (6 mL) at −78 °C was treated dropwise with *n*-BuLi in hexane (1.04 mL, 1.40 M, 1.460 mmol, 1.25 equiv), then the reaction mixture was warmed to room temperature. After 4 h it was added slowly dropwise to 3-*tert*-butyl-4-methoxycyclobutene-1,2-dione (195 mg, 1.159 mmol, 1.00 equiv) in THF (5 mL) at −78 °C and then 90 min later quenched with 10% aqueous NH_4Cl at −78 °C for 30 min. After warming to room temperature, the reaction mixture was washed with H_2O, extracted with Et_2O

(30 mL × 2), dried ($MgSO_4$), filtered, and concentrated, and the resulting yellow oil was chromatographed (flash column, silica gel, 2 × 10 cm, 25% ethyl acetate in hexane) to yield **12** as a light yellow solid (105 mg, 0.420 mmol, 29%). TLC: silica gel, 25% ethyl acetate in hexane, $R_f = 0.23$. Mp: 69−71 °C (Et_2O/hexane). IR (CH_2Cl_2, NaCl, cm^{-1}): 3564 (br, m), 1758 (s), 1618 (s). ^1H NMR ($CDCl_3$, 300 MHz): δ 6.30 (d, J = 3.0 Hz, 1 H), 5.94 (d, J = 3.0 Hz, 1 H), 4.92 (br s, 1 H), 3.99 (s, 3 H), 2.25 (s, 3 H), 1.20 (s, 9 H). ^{13}C NMR ($CDCl_3$, 75.5 MHz): δ 188.5, 179.4, 152.3, 148.4, 137.6, 108.8, 107.0, 88.5, 59.4, 31.1, 28.0 (3 C), 13.5. Anal. Calcd for $C_{14}H_{18}O_4$: C, 67.18; H, 7.25; O, 25.57. Found: C, 67.02; H, 7.23.

2-*tert*-Butyl-3-methoxy-4-[5-(2-methylfuryl)]-4-hydroxybutyric Acid γ-Lactone, 13. 2-*tert*-Butyl-4-hydroxy-3-methoxy-4-[5-(2-methylfuryl)]-2-cyclobutenone (57 mg, 0.228 mmol) was heated neat at 160 °C for 5.5 h. Chromatographic purification (flash column, silica gel, 1 × 8 cm, 25% ethyl acetate in hexane) yielded **13** as a yellow oil (43 mg, 0.172 mmol, 75%). TLC: silica gel, 25% ethyl acetate in hexane, R_f = 0.37). IR (CH_2Cl_2, NaCl, cm^{-1}): 1750 (s), 1653 (s). ^1H NMR ($CDCl_3$, 300 MHz): δ 6.34 (d, J = 3.3 Hz, 1 H), 5.99 (d, J = 3.3 Hz, 1 H), 5.72 (s, 1 H), 3.67 (s, 3 H), 2.29 (s, 3 H), 1.31 (s, 9 H). ^{13}C NMR ($CDCl_3$, 75.5 MHz): δ 171.8, 169.4, 154.0, 148.6, 145.2, 111.6, 107.0, 69.9, 57.3, 31.7, 28.8 (3 C), 13.6. Anal. Calcd for $C_{14}H_{18}O_4$: C, 67.18; H, 7.25; O, 25.57. Found: C, 67.24; H, 7.30.

2-*tert*-Butyl-3,4-dimethoxy-4-[5-(2-methylfuryl)]-2-cyclobutenone, 14. A mixture of 2-methylfuran (133 mg, 1.620 mmol, 1.40 equiv) and TMEDA (189 mg, 1.626 mmol, 1.40 equiv) in dry Et_2O (10 mL) at −78 °C was treated dropwise with *n*-BuLi in hexane (1.25 mL, 1.30 M, 1.630 mmol, 1.41 equiv), then the reaction mixture was warmed to room temperature. After 4 h it was added slowly dropwise to 3-*tert*-butyl-4-methoxycyclobutene-1,2-dione (195 mg, 1.159 mmol, 1.00 equiv) in THF (6 mL) at −78 °C and then 90 min later quenched with MeOTf (394 μL, 1.626 mmol, 3.00 equiv) at −78 °C for 30 min. After addition of H_2O, the reaction mixture was washed with H_2O, extracted with Et_2O (40 mL × 2), dried ($MgSO_4$), filtered, and concentrated to a yellow oil which was purified by chromatography (flash column, silica gel, 2 × 8 cm, 15% ethyl acetate in hexane) to yield **14** as a yellow oil (249 mg, 0.942 mmol, 81%). TLC: silica gel, 15% ethyl acetate in hexane, R_f = 0.31). IR (CH_2Cl_2, NaCl, cm^{-1}): 1757 (s), 1618 (s), 1561 (w). ^1H NMR ($CDCl_3$, 300 MHz): δ 6.27 (d, J = 3.0 Hz, 1 H), 5.92 (d, J = 3.0 Hz, 1 H), 3.96 (s, 3 H), 3.43 (s, 3 H), 2.23 (s, 3 H), 1.18 (s, 9 H). ^{13}C NMR ($CDCl_3$, 75.5 MHz): δ 186.6, 178.4, 152.3, 147.3, 139.0, 109.1, 106.7, 94.1, 59.3, 52.7, 31.2, 27.9 (3 C), 13.4. Anal. Calcd for $C_{15}H_{20}O_4$: C, 68.16; H, 7.63; O, 24.21. Found: C, 68.17; H, 7.59.

Electrocyclizations in the Presence of *n*-Bu_3N/Ac_2O. 2-*tert*-Butyl-4-(2-furyl)-3-isopropoxy-4-methoxy-2-cyclobutenone, 15. 2-Tri-*n*-butylstannylfuran (429 mg, 1.201 mmol, 1.20 equiv) in THF (6 mL) at −78 °C was treated dropwise with *n*-BuLi in hexane (1.05 mL, 1.14 M, 1.200 mmol, 1.20 equiv). The reaction mixture was warmed to 0 °C for 30 min and then added very slowly to 3-*tert*-butyl-4-isopropoxycyclobutene-1,2-dione (196 mg, 0.999 mmol, 1.00 equiv) in THF (6 mL) at −78 °C. After 20 min the reaction mixture was quenched at −78 °C with MeOTf (340 μL, 3.004 mmol, 3.01 equiv). After addition of H_2O, the reaction mixture was washed with H_2O, extracted with Et_2O (30 mL × 2), dried ($MgSO_4$), filtered, and concentrated to a yellow oil which was purified by chromatography (flash column, silica gel, 2 × 10 cm, 70% methylene chloride in hexane) to yield **15** as a colorless oil (224 mg, 0.805 mmol, 81%). TLC: silica gel, 70% methylene chloride in hexane, R_f = 0.35). IR (CH_2Cl_2, NaCl, cm^{-1}): 1755 (s), 1612 (s). ^1H NMR ($CDCl_3$, 300 MHz): δ 7.37 (br s, 1 H), 6.42 (d, J = 3.3 Hz, 1 H), 6.37 (dd, J = 3.3, 1.8 Hz, 1 H), 4.72 (sept, J = 6.0 Hz, 1 H), 3.47 (s, 3 H), 1.33 (d, J = 6.0 Hz, 3 H), 1.22 (s, 9 H), 1.02 (d, J = 6.0 Hz, 3 H). ^{13}C NMR ($CDCl_3$, 75.5 MHz): δ 186.3, 177.8, 149.6, 142.2, 139.6, 110.9, 108.2, 94.8, 77.7, 52.7, 31.4, 28.0 (3 C), 22.8, 22.5. Anal. Calcd for $C_{16}H_{22}O_4$: C, 69.04; H, 7.97; O, 22.99. Found: C, 68.96; H, 7.94.

4-Acetoxy-5-*tert*-butyl-6-isopropoxy-7-methoxybenzofuran, 16. 2-*tert*-Butyl-4-(2-furyl)-3-isopropoxy-4-methoxy-2-cyclobutenone, **15** (115 mg, 0.413 mmol, 1.00 equiv), *n*-Bu_3N (295 μL, 1.238 mmol, 3.00 equiv), Ac_2O (117 μL, 1.240 mmol, 3.00 equiv), and a catalytic amount of DMAP were dissolved in 3 mL of xylene and refluxed for 5 d. The reaction mixture was washed with 10% HCl, extracted with Et_2O (30 mL × 2), dried ($MgSO_4$), and concentrated to a yellow oil. The crude material was purified by chromatography (flash column, silica gel, 2 × 10 cm, 70% methylene chloride in hexane) to yield **16** as a yellow oil (118 mg, 0.368 mmol, 89%). TLC: silica gel, 70% methylene chloride in hexane, R_f = 0.60). IR (CH_2Cl_2, NaCl, cm^{-1}): 1758 (s), 1625 (w). ^1H NMR ($CDCl_3$, 300 MHz): δ 7.48 (d, J = 2.1 Hz, 1 H), 6.40 (d, J = 2.1 Hz, 1 H), 5.05 (sept, J = 6.3 Hz, 1 H), 4.04 (s, 3 H), 2.36 (s, 3 H), 1.50 (s, 9 H), 1.30 (d, J = 6.3 Hz, 6 H). ^{13}C NMR ($CDCl_3$, 75.5 MHz): δ 169.2, 146.1, 145.5, 143.9, 136.6, 136.3, 130.1, 118.4, 104.5, 73.6, 60.3, 36.5, 32.2 (3 C), 22.1 (2 C), 21.3. HRMS (EI) Calcd for $C_{18}H_{24}O_5$: 320.1623. Found: 320.1623.

5-*tert*-Butyl-4-hydroxy-6-isopropoxy-7-methoxybenzofuran, 17. 4-Acetoxy-5-*tert*-butyl-6-isopropoxy-7-methoxybenzofuran, **16** (51 mg, 0.159 mmol, 1.00 equiv), was dissolved in 5 mL of THF and cooled to 0 °C. $LiAlH_4$ (6 mg, 0.158 mmol, 0.99 equiv) powder was introduced and the solution was warmed to room temperature. After 5 min wet THF was added slowly to quench the excess $LiAlH_4$. The reaction mixture was washed with H_2O, extracted with Et_2O (20 mL × 2), dried ($MgSO_4$), filtered, and concentrated to a yellow oil which was purified by chromatography (flash column, silica gel, 2 × 10 cm, 25% ethyl acetate in hexane) to yield **18** as a yellow oil (44 mg, 0.158 mmol, 99%). TLC: silica gel, 25% ethyl acetate in hexane, R_f = 0.58). IR (CH_2Cl_2, NaCl, cm^{-1}): 3631 (br, m), 3592 (br, s), 1629 (w). ^1H NMR ($CDCl_3$, 300 MHz): δ 7.46 (d, J = 2.1 Hz, 1 H), 6.70 (d, J = 2.1 Hz, 1 H), 5.06 (br s, 1 H), 4.88 (sept, J = 6.3 Hz, 1 H), 3.98 (s, 3 H), 1.57 (s, 9 H), 1.28 (d, J = 6.3 Hz, 6 H). ^{13}C NMR ($CDCl_3$, 75.5 MHz): δ 146.8, 145.8, 143.2, 142.4, 133.3, 123.4, 114.2, 103.0, 73.7, 60.5, 36.3, 32.3 (3 C), 22.1 (2 C). HRMS (EI) Calcd for $C_{16}H_{22}O_4$: 278.1518. Found: 278.1518.

4-Hydroxy-6-isopropoxy-7-methoxybenzofuran, 20. 5-*tert*-Butyl-4-hydroxy-6-isopropoxy-7-methoxybenzofuran, **18** (76 mg, 0.273 mmol, 1.00 equiv), and anhydrous $Zn(OAc)_2$ (250 mg, 1.363 mmol, 4.99 equiv) were refluxed in 1.5 mL of HOAc for 150 min. Evaporation and chromatography (flash column, silica gel, 2 × 8 cm, 25% ethyl acetate in hexane) gave **20** as a yellow oil (57 mg, 0.256 mmol, 94%). TLC: silica gel, 25% ethyl acetate in hexane, R_f = 0.32). IR (CH_2Cl_2, NaCl, cm^{-1}): 3582 (s), 3380 (br, m), 1637 (m), 1505 (s). ^1H NMR ($CDCl_3$, 300 MHz): δ 7.46 (d, J = 2.1 Hz, 1 H), 6.78 (d, J = 2.1 Hz, 1 H), 6.35 (s, 1 H), 6.07 (s, 1 H), 4.40 (sept, J = 6.0 Hz, 1 H), 4.00 (s, 3 H), 1.29 (d, J = 6.0 Hz, 6 H). ^{13}C NMR ($CDCl_3$, 75.5 MHz): δ 148.7, 147.2, 144.0, 143.4, 130.8, 112.6, 103.6, 100.6, 73.5, 61.1, 22.2 (2 C). Anal. Calcd for $C_{12}H_{14}O_4$: C, 64.85; H, 6.35; O, 28.80. Found: C, 64.64; H, 6.44.

Synthesis of Acamelin, 22. **4-Acetoxy-5-*tert*-butyl-6,7-dimethoxy-2-methylbenzofuran, 17.** 2-*tert*-Butyl-3,4-dimethoxy-4-[5-(2-methylfuryl)]-2-cyclobutenone, **14** (98 mg, 0.371 mmol, 1.00 equiv), *n*-Bu_3N (177 μL, 0.743 mmol, 2.00 equiv), Ac_2O (70 μL, 0.742 mmol, 2.00 equiv), and catalytic amount of DMAP were dissolved in 3 mL of xylene and refluxed for 18 h. The reaction mixture was washed with 10% of HCl, extracted with Et_2O (20 mL × 2), dried ($MgSO_4$), and concentrated to a yellow oil. This crude material was purified by chromatography (flash column, silica gel, 2 × 8 cm, 15% ethyl acetate in hexane) to yield **17** as a yellow oil (92 mg, 0.300 mmol, 81%). TLC: silica gel, 15% ethyl acetate in hexane, R_f = 0.31). IR (CH_2Cl_2, NaCl, cm^{-1}): 1759 (s), 1607 (m). ^1H NMR ($CDCl_3$, 300 MHz): δ 6.03 (d, J = 0.9 Hz, 1 H), 4.11 (s, 3 H), 3.90 (s, 3 H), 2.40 (d, J = 0.9 Hz, 3 H), 2.33 (s, 3 H), 1.48 (s, 9 H). ^{13}C NMR ($CDCl_3$, 75.5 MHz): δ 169.4, 155.0, 148.8, 144.8, 137.0, 134.5, 129.3, 120.8, 100.3, 61.2, 60.3, 36.5, 32.0 (3 C), 21.2, 13.9. HRMS (EI) calcd for $C_{17}H_{22}O_5$ 306.1467, found 306.1460.

5-*tert*-Butyl-4-hydroxy-6,7-dimethoxy-2-methylbenzofuran, 19. 4-Acetoxy-5-*tert*-butyl-6,7-dimethoxy-2-methylbenzofuran, **17** (484 mg, 1.580 mmol, 1.00 equiv), was dissolved

in 30 mL of THF and cooled to 0 °C. $LiAlH_4$ (60 mg, 1.581 mmol, 1.00 equiv) powder was introduced in and the solution was warmed to room temperature. After 5 min wet THF was added slowly to quench extra $LiAlH_4$. The reaction mixture was washed with H_2O, extracted with Et_2O (40 mL × 2), dried ($MgSO_4$), filtered, and concentrated to a yellow oil which was purified by chromatography (flash column, silica gel, 3 × 10 cm, 15% ethyl acetate in hexane) to yield **19** as a light yellow solid (397 mg, 1.502 mmol, 95%). TLC: silica gel, 15% ethyl acetate in hexane, $R_f = 0.27$. Mp: 120−122 °C (methylene chloride/hexane). IR (CH_2Cl_2, NaCl, cm^{-1}): 3637 (m), 3592 (s), 1603 (m). ^1H NMR ($CDCl_3$, 300 MHz): δ 6.29 (s, 1 H), 5.26 (s, 1 H), 4.04 (s, 3 H), 3.86 (s, 3 H), 2.40 (s, 3 H), 1.57 (s, 9 H). ^{13}C NMR ($CDCl_3$, 75.5 MHz): δ 153.9, 149.2, 145.1, 141.4, 133.2, 122.3, 116.5, 98.9, 61.5, 60.6, 36.5, 32.0 (3 C), 13.9. Anal. Calcd for $C_{15}H_{20}O_4$: C, 68.16; H, 7.63; O, 24.21. Found: C, 68.06; H, 7.63.

4-Hydroxy-6,7-dimethoxy-2-methylbenzofuran, 21. 5-*tert*-Butyl-4-hydroxy-6,7-dimethoxy-2-methylbenzofuran, **19** (358 mg, 1.354 mmol, 1.00 equiv), and anhydrous $Zn(OAc)_2$ (1.24 g, 6.770 mmol, 5.00 equiv) were refluxed in 10 mL of HOAc for 10 h. Evaporation and chromatography (flash column, silica gel, 3 × 10 cm, 25% ethyl acetate in hexane) gave **21** as a white solid (247 mg, 1.186 mmol, 88%). TLC: silica gel, 25% ethyl acetate in hexane, $R_f = 0.25$. Mp: 150−151 °C (Et_2O/hexane). IR (CH_2Cl_2, NaCl, cm^{-1}): 3583 (br, s),1612 (m), 1518 (s). ^1H NMR (CD_3OD, 300 MHz): δ 6.36 (d, $J = 0.9$ Hz, 1 H), 6.30 (s, 1 H), 4.88 (br s, 1 H), 3.86 (s, 3 H), 3.77 (s, 3 H), 2.34 (d, $J = 0.9$ Hz, 3 H). ^{13}C NMR (CD_3OD, 75.5 MHz): δ 154.6, 150.3, 149.7, 146.3, 129.3, 114.7, 100.9, 97.0, 61.7, 57.8, 13.9. Anal. Calcd for $C_{11}H_{12}O_4$: C, 63.45; H, 5.81; O, 30.74. Found: C, 63.34; H, 5.85.

Acamelin, 6-Methoxy-2-methylbenzo[*b*]furandione, 22. 4-Hydroxy-6,7-dimethoxy-2-methylbenzofuran, **21** (70 mg, 0.336 mmol, 1.00 equiv), in 10 mL of CH_3CN was treated with 10 mL of 0.067 N aqueous ammonium cerium(IV) nitrate solution at room temperature. After 10 min, the reaction mixture was extracted with Et_2O (30 mL) and $CHCl_3$ (30 mL × 2), and the combined organic layers were dried ($MgSO_4$), filtered, and concentrated to an orange solid. Recrystallization from chloroform−acetone gave **22** as an orange-red solid (63 mg, 0.328 mmol, 98%). TLC: silica gel, 25% ethyl acetate in hexane, $R_f = 0.29$. Mp: 250−252 °C ($CHCl_3$−acetone; lit.[19] mp 253−255 °C). IR (CH_2Cl_2, NaCl, cm^{-1}): 1686 (s), 1659 (s), 1607 (s), 1578 (s), 1539 (s). ^1H NMR ($CDCl_3$, 300 MHz): δ 6.42 (d, $J = 0.9$ Hz, 1 H), 5.76 (s, 1 H), 3.83 (s, 3 H), 2.44 (d, $J = 0.9$ Hz, 3 H). ^{13}C NMR ($CDCl_3$, 75.5 MHz): δ 182.2, 168.7, 161.1, 159.6, 148.6, 131.1, 106.6, 104.9, 56.9, 14.1. Anal. Calcd for $C_{10}H_8O_4$: C, 62.50; H, 4.20; O, 33.30. Found: C, 62.36; H, 4.28. Spectral data matched those reported in the literature.[19]

Synthesis of Ring-fused Pyridones 23. Typical Procedure. 8-Acetoxy-6-*tert*-butyl-7-isopropoxythiazolo[3,2-*a*]pyridin-5-one, 23a. 2-Tri-*n*-butylstannylthiazole (449 mg, 1.200 mmol, 1.20 equiv) in THF (5 mL) at −78 °C was treated dropwise with *n*-BuLi in hexane (1.00 mL, 1.25 M, 1.250 mmol, 1.25 equiv). After warming to 0 °C for 30 min, the solution was added very slowly dropwise to 3-*tert*-butyl-4-isopropoxycyclobutene-1,2-dione (196 mg, 0.999 mmol, 1.00 equiv) in dry THF (5 mL) at −78 °C. After 40 min, the reaction was quenched with Ac_2O (283 μL, 2.999 mmol, 3.00 equiv) and held at −78 °C for 30 min. After warming to room temperature, the reaction mixture was rapidly washed with H_2O, extracted with Et_2O (50 mL × 2), dried ($MgSO_4$), filtered, and concentrated to a brown oil that was heated neat in a flame-dried flask (120 °C, 40 min) and then purified by chromatography (flash column, silica gel, 2 × 15 cm, 25% ethyl acetate in hexane) to yield **23a** as a yellow oil (204 mg, 0.631 mmol, 63%). TLC: silica gel, 25% ethyl acetate in hexane, $R_f = 0.22$). IR (CH_2Cl_2, NaCl, cm^{-1}): 1780 (s), 1645 (s), 1585 (s), 1477 (s). ^1H NMR ($CDCl_3$, 300 MHz): δ 8.01 (d, $J = 4.5$ Hz, 1 H), 6.76 (d, $J = 4.5$ Hz, 1 H), 4.60 (sept, $J = 6.3$ Hz, 1 H), 2.31 (s, 3 H), 1.48 (s, 9 H), 1.29 (d, $J = 6.3$ Hz, 6 H). ^{13}C NMR ($CDCl_3$, 75.5 MHz): δ 167.3, 158.5, 156.7, 137.3, 124.8, 123.1, 121.1, 109.7, 76.2, 36.2, 30.4 (3 C), 22.2 (2 C), 20.3. Anal. Calcd for $C_{16}H_{21}NSO_4$: C, 59.42; H, 6.54; N, 4.33; S, 9.91; O, 19.79. Found: C, 59.65; H, 6.59; N, 4.09.

The experimental details and characterization data for compounds **23b**−**g** are found in the Supporting Information.

Synthesis of 24 by Acid-Catalyzed Removal of *tert*-Butyl Substituents from 23. 8-Acetoxy-7-isopropoxythiazolo[3,2-*a*]pyridin-5-one, 24a. 8-Acetoxy-6-*tert*-butyl-7-isopropoxythiazolo[3,2-a]pyridin-5-one (58 mg, 0.179 mmol, 1.00 equiv) and anhydrous $Zn(OAc)_2$ (165 mg, 0.899 mmol, 5.02 equiv) in 3 mL of HOAc were refluxed for 9 h. The liquid phase was removed by a pipet and the solvent was evaporated. Chromatographic purification (flash column, silica gel, 0.5 × 10 cm, ethyl acetate) provided **24a** as a brown oil (45 mg, 0.168 mmol, 94%). TLC: silica gel, ethyl acetate, $R_f = 0.38$). IR (CH_2Cl_2, NaCl, cm^{-1}): 3124 (w), 3054 (m), 2984 (m), 1782 (s), 1662 (s), 1591 (s), 1497 (s), 1472 (m), 1464 (m), 1371 (m), 1331 (m), 1215 (m), 1185 (m), 1150 (m), 1108 (m). ^1H NMR (C_6D_6, 300 MHz): δ 7.70 (d, $J = 4.5$ Hz, 1 H), 5.85 (s, 1 H), 5.58 (d, $J = 4.5$ Hz, 1 H), 4.04 (sept, $J = 6.0$ Hz, 1 H), 1.82 (s, 3 H), 0.94 (d, $J = 6.0$ Hz, 6 H). ^{13}C NMR (C_6D_6, 75.5 MHz): δ 167.4, 159.3, 158.5, 140.7, 124.5, 120.2, 108.6, 91.8, 71.7, 21.4 (2 C), 19.6. Anal. Calcd for $C_{12}H_{13}NSO_4$: C, 53.92; H, 4.90; N, 5.24; S, 12.00; O, 23.94. Found: C, 53.95; H, 4.99; N, 5.17.

8-Acetoxy-7-methylthiazolo[3,2-*a*]pyridin-5-one, 24b. 8-Acetoxy-6-*tert*-butyl-7-methylthiazolo[3,2-a]pyridin-5-one (56 mg, 0.200 mmol, 1.00 equiv) and anhydrous $Zn(OAc)_2$ (368 mg, 2.006 mmol, 10.03 equiv) in 3 mL of HOAc were refluxed for 10 h. Evaporation and chromatography (flash column, silica gel, 1 × 10 cm, ethyl acetate) provided **24b** as a silver gray solid (41 mg, 0.184 mmol, 92%). TLC: silica gel, ethyl acetate, $R_f = 0.21$. Mp: 208−209 °C (methylene chloride/hexane). IR (CH_2Cl_2, NaCl, cm^{-1}): 3123 (w), 2983 (w), 1784 (s), 1671 (s), 1582 (s), 1494 (s), 1452 (m), 1373 (m), 1333 (w), 1204 (s), 1182 (s), 1127 (m). ^1H NMR ($CDCl_3$, 300 MHz): δ 8.08 (d, $J = 4.5$ Hz, 1 H), 6.90 (d, $J = 4.5$ Hz, 1 H), 6.23 (s, 1 H), 2.36 (s, 3 H), 2.15 (s, 3 H). ^{13}C NMR ($CDCl_3$, 75.5 MHz): δ 168.1, 158.0, 144.0, 140.0, 127.2, 125.0, 111.0, 109.7, 20.2, 16.7. Anal. Calcd for $C_{10}H_9NO_3S$: C, 53.80; H, 4.06; N, 6.27; O, 21.50; S, 14.36. Found: C, 53.59; H, 4.11; N, 5.99.

8-Acetoxy-7-diethylaminothiazolo[3,2-*a*]pyridin-5-one, 24c. 8-Acetoxy-6-*tert*-butyl-7-diethylaminothiazolo[3,2-a]pyridin-5-one (125 mg, 0.372 mmol, 1.00 equiv) and anhydrous $Zn(OAc)_2$ (341 mg, 1.859 mmol, 5.00 equiv) in 2 mL of HOAc were refluxed for 10 min. Evaporation and chromatography (flash column, silica gel, 1 × 5 cm, ethyl acetate to 10% methanol in ethyl acetate) provided **24c** as a brown oil (104 mg, 0.371 mmol, 100%). TLC: silica gel, 25% methanol in ethyl acetate, $R_f = 0.67$). IR (CH_2Cl_2, NaCl, cm^{-1}): 3125 (w), 3050 (w), 2982 (m), 1779 (s), 1650 (s), 1582 (s), 1552 (m), 1508 (m), 1465 (s), 1382 (w), 1369 (m), 1336 (w), 1188 (s), 1168 (m), 1126 (m), 1019 (w). ^1H NMR ($CDCl_3$, 300 MHz): δ 7.84 (d, $J = 4.5$ Hz, 1 H), 6.64 (d, $J = 4.5$ Hz, 1 H), 5.64 (s, 1 H), 3.27 (q, $J = 7.2$ Hz, 4 H), 2.26 (s, 3 H), 1.11 (t, $J = 7.2$ Hz, 6 H). ^{13}C NMR ($CDCl_3$, 75.5 MHz): δ 167.4, 157.9, 151.4, 141.9, 124.3, 119.9, 108.5, 93.2, 45.2 (2 C), 20.4, 12.6 (2 C). Anal. Calcd for $C_{13}H_{16}N_2SO_3$: C, 55.70; H, 5.75; N, 9.99; S, 11.44; O, 17.12. Found: C, 55.85; H, 5.87; N, 9.88.

4-Acetoxy-3-isopropoxy-1-oxopyrido[2,1-*b*]benzothiazole, 24d. 4-Acetoxy-2-*tert*-butyl-3-isopropoxy-1-oxopyrido-[2,1-b]benzothiazole (90 mg, 0.241 mmol, 1.00 equiv) and anhydrous $Zn(OAc)_2$ (221 mg, 1.205 mmol, 5.00 equiv) in 3 mL of HOAc were refluxed for 21 h. Evaporation and chromatography (flash column, silica gel, 1 × 15 cm, 25% ethyl acetate in hexane) provided **24d** as a light yellow solid (65 mg, 0.205 mmol, 85%). TLC: silica gel, 25% ethyl acetate in hexane, $R_f = 0.17$. Mp: 133−134 °C (methylene chloride/hexane). IR (CH_2Cl_2, NaCl, cm^{-1}): 3054 (m), 2985 (m), 1779 (s), 1667 (s), 1604 (s), 1576 (m), 1521 (s), 1473 (w), 1465 (w), 1454 (s), 1205 (m), 1179 (m), 1108 (m), 1084 (w), 1030 (m). ^1H NMR ($CDCl_3$, 300 MHz): δ 9.13 (d, $J = 8.4$ Hz, 1 H), 7.53 (d, $J = 7.8$ Hz, 1 H), 7.43 (app t, $J = 7.8$ Hz, 1 H), 7.35 (app t, $J = 7.5$ Hz, 1 H), 5.90 (s, 1 H), 4.63 (sept, $J = 6.0$ Hz, 1 H), 2.32 (s, 3 H), 1.36 (d, $J = 6.0$ Hz, 6 H). ^{13}C NMR ($CDCl_3$, 75.5 MHz): δ 167.8, 162.1, 158.4, 139.2, 138.8, 126.5, 125.9, 125.4, 121.4, 120.5, 119.8, 93.9, 72.1, 21.5 (2 C), 20.0. Anal. Calcd for $C_{16}H_{15}$-

NSO_4: C, 60.55; H, 4.76; N, 4.41; S, 10.10; O, 20.17. Found: C, 60.62; H, 4.79; N, 4.32.

4-Acetoxy-3-methyl-1-oxopyrido[2,1-*b*]benzothiazole, 24e. 4-Acetoxy-2-*tert*-butyl-3-methyl-1-oxopyrido[2,1-b]benzothiazole (60 mg, 0.182 mmol, 1.00 equiv) and anhydrous $Zn(OAc)_2$ (334 mg, 1.821 mmol, 10.01 equiv) in 3 mL of HOAc were refluxed for 12 h. Evaporation and chromatography (flash column, silica gel, 1 × 10 cm, ethyl acetate) provided **24e** as a yellow solid (47 mg, 0.172 mmol, 95%). TLC: silica gel, ethyl acetate, R_f = 0.50. Mp: 190−191 °C (methylene chloride/hexane). IR (CH_2Cl_2, NaCl, cm^{-1}): 3052 (w), 2987 (w), 1774 (s), 1673 (s), 1598 (s), 1576 (m), 1509 (s), 1449 (m), 1372 (w), 1265 (s), 1198 (s), 1154 (m). ^{1}H NMR ($CDCl_3$, 300 MHz): δ 9.24 (dd, J = 8.4, 0.9 Hz, 1 H), 7.59 (dd, J = 7.5, 0.9 Hz, 1 H), 7.47−7.36 (m, 2 H), 6.33 (s, 1 H), 2.37 (s, 3 H), 2.15 (s, 3 H). ^{13}C NMR ($CDCl_3$, 75.5 MHz): δ 168.2, 161.0, 144.1, 139.0, 138.4, 127.3, 126.5, 126.4, 125.6, 121.4, 120.3, 113.3, 20.2, 16.5. Anal. Calcd for $C_{14}H_{11}NO_3S$: C, 61.53; H, 4.06; N, 5.12; O, 17.56; S, 11.73. Found: C, 61.25; H, 4.24; N, 4.93.

8-Acetoxy-7-isopropoxy-1-methylimidazo[1,2-*a*]pyridin-5-one, 24f. 8-Acetoxy-6-*tert*-butyl-7-isopropoxy-1-methylimidazo[1,2-a]pyridin-5-one (61 mg, 0.190 mmol, 1.00 equiv) and anhydrous $Zn(OAc)_2$ (349 mg, 1.902 mmol, 10.01 equiv) in 2 mL of HOAc were refluxed for 4 h. Evaporation and chromatography (flash column, silica gel, 1 × 10 cm, 20% MeOH in ethyl acetate) provided **24f** as a brown oil (50 mg, 0.189 mmol, 99%). TLC: silica gel, 20% MeOH in ethyl acetate, R_f = 0.25). IR (CH_2Cl_2, NaCl, cm^{-1}): 3053 (m), 2983 (m), 1774 (s), 1673 (s), 1593 (s), 1567 (s), 1530 (s), 1467 (m), 1443 (m), 1372 (m), 1332 (w), 1306 (w), 1231 (s), 1210 (m), 1194 (m), 1157 (s), 1110 (m), 1055 (m). ^{1}H NMR ($CDCl_3$, 300 MHz): δ 7.53 (d, J = 2.1 Hz, 1 H), 6.71 (d, J = 2.1 Hz, 1 H), 5.62 (s, 1 H), 4.55 (sept, J = 6.0 Hz, 1 H), 3.67 (s, 3 H), 2.28 (s, 3 H), 1.28 (d, J = 6.0 Hz, 6 H). ^{13}C NMR ($CDCl_3$, 75.5 MHz): δ 169.7, 158.2, 155.5, 135.5, 121.3, 108.2, 107.8, 85.0, 71.4, 34.4, 21.8 (2 C), 20.1. Anal. Calcd for $C_{13}H_{16}N_2O_4$: C, 59.08; H, 6.10; N, 10.60; O, 24.22. Found: C, 58.99; H, 6.06; N, 10.49.

8-Acetoxy-1,7-dimethylimidazo[1,2-*a*]pyridin-5-one, 24g. 8-Acetoxy-6-*tert*-butyl-1,7-dimethylimidazo[1,2-a]pyridin-5-one (100 mg, 0.362 mmol, 1.00 equiv) and anhydrous $Zn(OAc)_2$ (664 mg, 3.619 mmol, 10.00 equiv) in 2 mL of HOAc were refluxed for 3 h. Evaporation and chromatography (flash column, silica gel, 1 × 6 cm, 25% methanol in ethyl acetate) provided **24g** as a yellow oil (74 mg, 0.336 mmol, 93%). TLC: silica gel, 25% methanol in ethyl acetate, R_f = 0.42). IR (CH_2Cl_2, NaCl, cm^{-1}): 3055 (m), 2983 (w), 1771 (s), 1669 (s), 1580 (s), 1560 (s), 1524 (s), 1430 (m), 1372 (m), 1335 (w), 1296 (w), 1274 (s), 1201 (s), 1133 (s). ^{1}H NMR ($CDCl_3$, 300 MHz): δ 7.70 (d, J = 2.1 Hz, 1 H), 6.84 (d, J = 2.1 Hz, 1 H), 5.83 (s, 1 H), 3.76 (s, 3 H), 2.36 (s, 3 H), 2.09 (s, 3 H). ^{13}C NMR ($CDCl_3$, 75.5 MHz): δ 170.0, 154.5, 141.8, 134.7, 122.0, 115.7, 108.9, 99.7, 34.6, 20.3, 16.4. Anal. Calcd for $C_{11}H_{12}N_2O_3$: C, 59.99; H, 5.49; N, 12.72; O, 21.79. Found: C, 59.64; H, 5.89; N, 13.00.

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Supporting Information Available: A complete description of the synthesis and characterization of compounds **8b**−**i**, **9b**−**i**, and **23b**−**g** and copies of the ^{1}H NMR data for *N*-methyl-2-tri-*n*-butylstannylindole and the unstable compounds **7a** and **7f**, for which elemental analyses were not obtained, and ^{1}H and ^{13}C NMR data for **8i**, **16**, **17**, and **18,** for which HRMS and not elemental analyses were obtained (22 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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